DEPARTMENT OF THE ARMY CORPS OF ENGINEERS

BEACH EROSION BOARD
OFFICE OF THE CHIEF OF ENGINEERS

DUNE FORMATION AND STABILIZATION BY VEGETATION AND PLANTINGS

TECHNICAL MEMORANDUM NO. 101

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OCTOBER 1957

FOREWORD

An important feature of the general investigations program of the Beach Erosion Board is the assembly of data to facilitate selection and employment of plants for the economic stabilization of coastal dunes. No earlier reports have been published by the Board on this subject. The following report concerns the use of plants for building and stabilizing dunes. Several service records of such use are included.

The report has been prepared by Dr. John H. Davis of the Botany Department of the University of Florida in pursuance of Contract DA 49-055-CIV ENG-57-3 with the Beach Erosion Board. Mr. Jay V. Hall, Jr., Chief of the Engineering Division, was the Beach Erosion Board's representative on the project.

At the time the report was completed the technical staff of the Beach Erosion Board was under the supervision of Major General Charles G. Holle, President of the Board, Colonel Allen A. Futral, Executive, and R. O. Eaton, Chief Technical Advisor. The report was edited for publication by A. C. Rayner, Chief of the Project Development Division, and N. E. Taney, Chief of the Geology Branch, Engineering Division.

Views and conclusions stated in the report are not necessarily those of the Beach Erosion Board.

This report is published under the authority of Public Law 166, 79th Congress, approved July 31, 1945.

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Frontispiece: Dune Formations at Cape Hatteras National Seashore Recreational Area, North Carolina. Two dune ridges separated by a broad swale. The seaward ridge is stabilized by grasses and the higher ridge by scrub vegetation. Courtesy of National Park Service.

DUNE FORMATION AND STABILIZATION BY VEGETATION AND PLANTINGS

by
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INTRODUCTION

Ample experience in the United States and Europe shows that plantings and management of extant vegetation are effective in promoting dune formation and in the stabilization of dunes. Dunes may form, of course, with or without plant life; however, where the climate of the coastal region is conducive to plant growth, the plants play an active role in the development and eventual stabilization of the dune formations. Dune stabilization by plant life is effected particularly by the underground parts of the plant holding the material; however, the aerial parts are also important as they increase the surface roughness of the land form and thereby affect the movement of sand by winds. The purpose of this paper is to discuss the effectiveness of various plants in dune formation and stabilization.

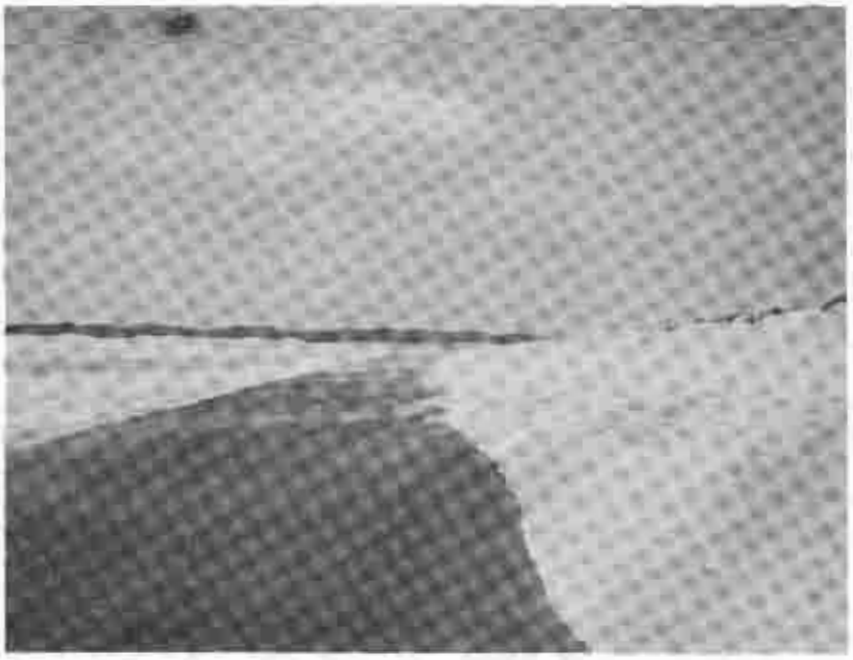
IMPORTANCE OF DUNES FOR SHORE PROTECTION

Dune ridges along the coast are the high barriers against the action of normal and storm tides and waves. They check storm waters from flooding the low interior areas; and they also reduce the action of onshore winds, which would erode more of the interior of the coast if no obstruction were present. Other dune ridges and dune fields farther inland also are protective to a lesser degree than the frontal barrier dunes. If they are well stabilized they serve as a second line of defense against water and wind erosion, should the foredunes be destroyed by storm wave action. Suitable stabilization measures hold sand in place, sand that might ordinarily migrate over adjacent areas and damage improved property. Figure 1 illustrates these features.

The dunes near the beaches are not only barriers against high water and strong onshore winds but their role as stockpiles is most important. Deposition often accumulates on the seaward slope rapidly enough to extend the dune outward toward the beach. This material may be returned to the foreshore by wave action on a high tide and thus serves to nourish the beach.

Dunes on barrier beaches which flank long reaches of many coasts, such as the Outer Banks of North Carolina and the coast of Texas, often prevent storms from breaching these barriers. In some areas where the dune crest is not continuous the storm waters have poured through the gaps and made cuts across the islands. Subsequently, some of these cuts have widened and deepened into inlets which have interrupted the longshore drift enough to starve beaches downdrift from the inlet. Dune ridges

High, well-stabilized barrier dune



Migration of unstabilized dune across a road

Figure 1 Stabilized and Migrating Dunes at Cape Hatteras National Seashore Recreational Area, North Carolina. Courtesy of National Park Service

are a very important protection on such coasts and many are now being built and maintained to prevent such breaching.

FORMATION OF DUNES

Dunes occur in areas where a substantial supply of sand is available and meteorological conditions are proper. Both of these conditions are fulfilled on many of the wide sandy beaches fronting the coast of the United States.

Winds of sufficient velocity to move the sand particles erode the dry portions of a beach and transport the sand in three ways:

a. suspension, whereby the small or low density grains are lifted high into the air stream and carried for appreciable distances;

b. saltation, whereby the wind carries an individual particle close to the surface for some short distance through a definite curved path; and

c. surface creep, whereby a relatively large particle rolls or bounces along the ground as a result of wind pressure or the impact of a descending saltating particle.

The three modes of transportation effectively sort the original beach material. The small particles may be completely removed from the dune area while the largest particles remain; therefore, the dunes are composed of material of essentially one size. This uniformity of size materially aids the development of a vegetative cover.

The building of a dune begins where an obstruction causes deposition of the suspended particles and stops saltating or creeping particles. As the incipient dune builds, its slope becomes sufficiently steep so that saltating or creeping particles come to rest on its windward slope. With higher wind velocities particles will fall over the crest of the dune, resulting in migration of the dune in the same direction as that of the wind. Under favorable conditions of material supply and wind action, dunes build to heights far above the maximum elevation of storm wave action, and several dune ridges may be formed. The formation of dunes may be started and their enlargement may be accelerated by the use of sand fences or planting. Artificial dunes are also constructed in some cases by mechanical or hydraulic placement of fill.

ROLE OF VEGETATION IN DUNE FORMATION AND STABILIZATION

Plant life in the form of single plants, groups of plants, and sparse to dense vegetation of herbs, shrubs, and trees aids in the development of the topographic forms of the coast and parts of some backshores. The plant life is secondary to the mechanical forces in the development

of some of the dune topography, but it is most important in the stabilization and retention of the various forms after they have been developed. Plants are passive agents that alter wind action, but they are active agents in holding dune materials in place. They also aid in the processes that change these materials to soils. Physiographic processes would not approach nor attain the equilibrium status common along many coasts without plants that arrest wind, stop or retard shifting of materials, and add organic soil components. Each coastal plant plays a particular role, but it is usually the aggregation of plants that brings about changes and consequent stabilization.

Plants influence the wind and erosion and deposition by two major methods: (1) their aerial parts act as obstructions, increasing the roughness of the surface, and deflect or screen wind movement; and (2) the underground parts tend to bind and hold the materials in place. In addition, plants affect the water content of the soil and their decomposition adds humus to the soil. Groups of plants forming a vegetative cover may be sufficiently dense to alter wind action enough to prevent all but very minor erosion and deposition. In this manner the vegetation stabilizes the topographic forms against all but the most violent action of wind or rain.

The primary role of plants along the foredunes, however, is more important as individualsor small groups than as a dense cover. The pioneer, dune-forming plants influence the movement of wind-borne sand and generally cause more deposition in an area than would normally occur if they were not present. The screening effect of the generally flexible, aerial parts of plants upon the wind is accomplished by deflecting the wind and decreasing its velocity. Some of the material moving by saltation and surface creep is arrested and deposited around the plant. The deposition continues around and eventually on top of the plant and may lead to burial or partial burial of the plant. Unless the tops continue to grow more rapidly than the deposition occurs, the arresting action of the plant ceases. The vigorous growth of the top parts is often characteristic of the pioneer, dune-forming plants. Even when dead, the exposed upper parts of the plant may continue to act as screens. This is true of some annual and some perennial plants which die or only die back during the winter season. The rapid growing herbaceous plants are most effective as screening agents, while the woody plants of the scrub and forest zones of vegetation are the best permanent obstructions, and in some areas the latter cause the greatest deposition.

The mechanical and other effects of the underground parts of plants are complex. The fibrous root systems and adventitious roots from the joints or nodes along the stem act as very efficient sand binders. The rhizomes or rootstocks below the surface and the stolons or runners at or near the surface also serve in the same capacity. The total of these underground and near surface parts is often greater than that of the aerial parts. Usually they are of small diameter but very extensive and grow

downward to zones of damp or wet soils. The extensive root systems through the dry and wet zones hold the sand and prevent erosion by wind action. Root systems are illustrated in Figure 2.

The underground parts absorb water and also selectively absorb some of the minerals present. This alteration of the moisture content and chemical characteristics is a slow but significant change in the sands of dune fields of long duration. The shade produced by plants keeps temperatures lower than those present in uncovered sand and, therefore, reduces the evaporation of water. The addition of the dead aerial parts of plants to the surface acts as a mulch and also increases the organic content of the sand, thereby changing the chemical conditions. These changes gradually lead to an increase in the vegetative cover and a consequent decrease in the mobility of the dune sands.

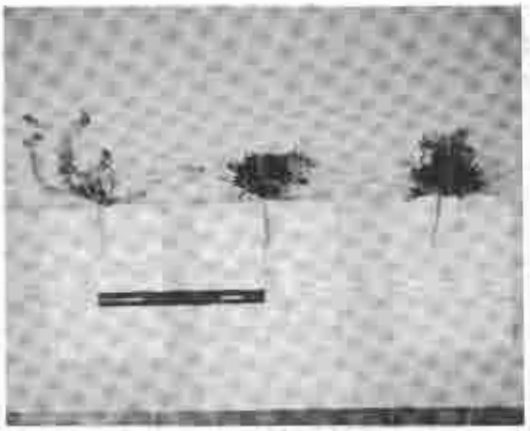
Plants have the ability of growth extension in three directions; horizontally, upward, and downward. In this manner they may keep pace with deposition and continue to alter the erosion - deposition cycle. Plants accomodate themselves to changes in wind direction and to the shifting of the sandy soils. The aerial parts are less apt to grow as rapidly as the underground parts during active movement of sand and may not survive adverse conditions of strong winds, flooding, salt spray, and cold or dry weather. However, the ability of plants to survive and procreate themselves makes them nearly perpetual agents for stabilization.

TYPES OF VEGETATION

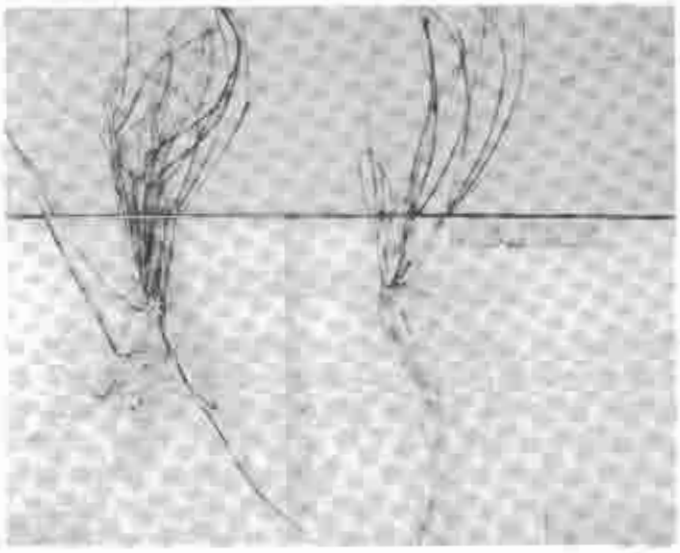
The aggregations of plants in a coastal zone form, in general, three types of vegetative cover: (1) a pioneer type composed mostly of herbaceous plants; (2) a scrub type of woody shrubs and vines and dwarf form trees with a few associated herbs; and (3) a forest type dominated by trees. Figure 3 shows such a development. Many coasts have some succulent, semi-woody, and fibrous-leaved plants and palms in the first two types of vegetation. Nearly all of the plants of the first two types are tolerant to salt spray and various degrees of salinity of the soil, and are known as halophytes.

These three types of vegetation usually occur in narrow zones over the broad coast. The pioneer herbaceous vegetation is on the dune fields nearest the beach. The scrub vegetation is found on the partly to fully stabilized older dunes, in some of the valley swales and on some of the flats. The forest vegetation is toward the interior on the oldest and most stable dune fields. It is not always present, but when present it covers the dunes, swales, and flats that have been stabilized for a long time and have soils with several distinctly different layers that were partly developed by the pioneer and scrub vegetation.

Pioneer Type. The herbaceous, pioneer vegetation is the chief dune-forming agent. These plants are known as the pioneers because they grow in a manner that enables them to help develop dunes in conjunction with



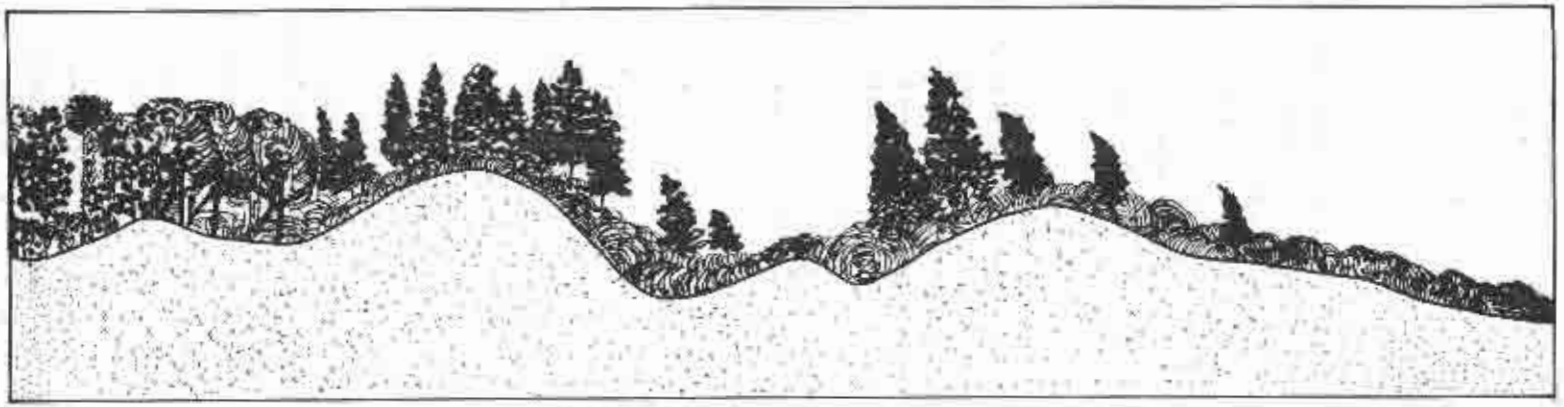
Undesirable root system for sand stabilization



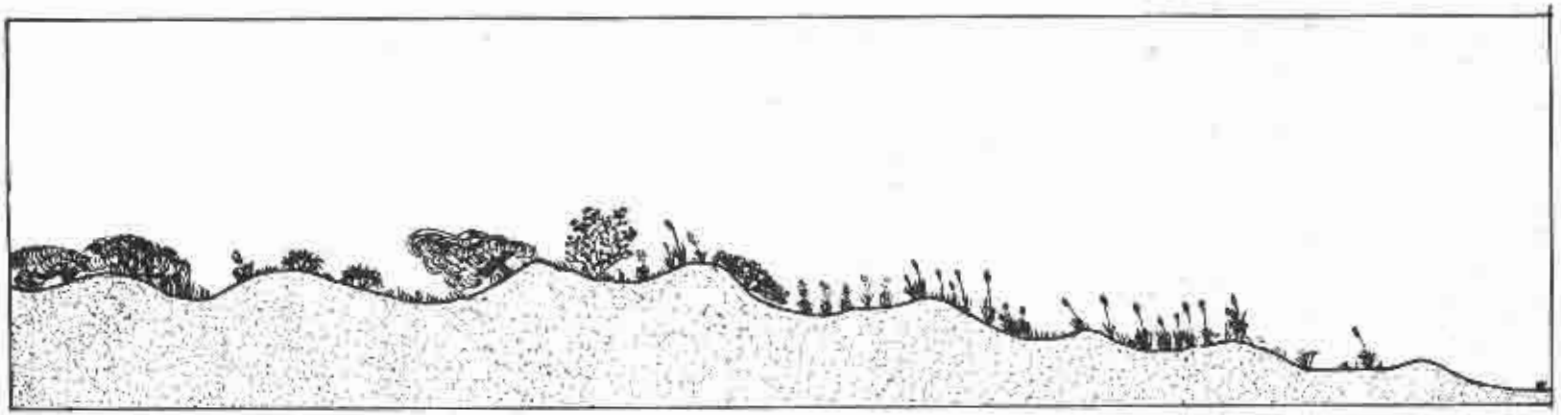
Sporobolus Virginicus
Desirable extensive root system for sand stabilization

Sand stabilization employing plants with desirable root systems

Figure 2 Root Systems



HARDWOOD FOREST PINE FOREST AND SCRUB SCRUB ZONE WITH A FEW PINES



SCRUB ZONE MIXED PIONEERS AND SCRUB PIONEER ZONE DRIFT LINE

FIGURE 3. TYPES OF VEGETATION OVER BROAD COAST.

wind action. The upper beach and drift line plants grow where wave and tidal action may occur and some of them die as a result of storms. They begin the formation of low ridges and embryonic dunes at the drift line by retarding some water and wind action. However, most of the pioneer plants are on the front slope, top, and back slope of the first dune ridge or series of dune mounds back from the beach.

The pioneer plants are mostly grasses that have strong, wide-spreading rootstocks or rhizomes underground, and runners or stolons near or over the surface. The most effective of these plants are fibrous rooted perennials with some of the following characteristics: (1) a rapid lateral spread by horizontal surface or underground stems; (2) rapid vertical growth by upright stems, and the stems and culms thus elongating usually grow upward as fast as materials collect around them; and (3) stems that usually develop roots at higher and higher levels from the joints or nodes.

The best dune-forming plants have both the horizontally and vertically elongating stems, but some of the common pioneers have only one of these characteristics. Some plants do not have wide-spreading lateral stems; however, these plants are effective when they have closely grouped stems that form a compact bunch or cespitose growth form. Some of these plants that are not grasses, such as the composite flowered type plants, have many shoots from one taproot system, and a few of these are effective in building low, dome-shaped mounds, but they do not aid much in the formation of long, high dune ridges.

Pioneer plants are the initial vegetation of the coastal succession or sequence of vegetation that finally develops into a forest. They increase the rate and height of dune formation and determine the pattern of development of the coastal zone, but usually they do not complete the stabilization of the dune fields. This is because, generally, they do not form a sufficiently dense plant cover to prevent the movement of sand and other materials. They prepare the soil, the soil water, and the soil humus for a denser growth of plants. Small woody plants replace them slowly and eventually cover the area they occupied to form a scrub type of vegetation that stabilizes most dune fields.

Therefore, the pioneer vegetation does two things: (1) it initiates the formation of dune fields by decreasing the movement of coastal materials and causing deposition, and (2) it prepares the soil and other habitat conditions for the development of the scrub vegetation. The first function or role is mostly mechanical by binding the soil and retarding winds, and consequently the pioneer plants are most important in building up and extending dunes. Figure 4 illustrates pioneer and scrub zone vegetation.

Scrub Type. Scrub vegetation usually begins on the second, third or more interior dune ridge, and may extend over a number of swales and flats of interior areas. It is a sparse to very dense growth of shrubs, woody

Figure 4 Pioneer and Scrub Zone Vegetation at Cape Hatteras National Seashore Recreational Area, North Carolina. Pioneer grasses in foreground and shrubs of scrub zone on right and in background. Courtesy of National Park Service.

vines, stunted trees, and scattered herbs. Where the scrub growth is dense, the land forms are well stabilized. Some scrub zones have bare areas of sand caused by natural or human disturbances of the vegetation and soils. The chief natural disturbances are excessive salt spray, storm waters, fire, and animals. Man has altered many areas by fire, construction, and promoted grazing. The worst of the altered areas have large blow-outs and migrating dunes. These zones usually need management and protection to preserve the vegetation so that the dunes may be stabilized. When scrub areas are seriously disturbed, pioneer plants are needed to redevelop the vegetation on them, as scrub plants often cannot be restored directly in areas of moving sand.

Most of the bushes, shrubs, low palms, fibrous-leaved and succulent plants, dwarfed trees, and woody vines of this zone are facultative halophytes, those which can withstand some salt spray and some soil salinity but are injured or killed by concentrations of these. The salt spray and the winds along the coast prune and sculpture the shrubs and trees. The soils are more moist than those of the pioneer zone, but most of the species are xerophytes, plants which are able to endure in low concentrations of atmospheric and soil moisture.

The heath or heather form of shrub growth is common. Members of the heath family are abundant along the cool to cold coastal regions. Members of other families also assume this heath form, and are found along northern and central parts of the Atlantic coast. There are numerous dwarf oaks in the southern Atlantic and Gulf of Mexico regions. The cactus type and fibrous-leaved plants are common along hot and dry coasts, such as in southern Florida, southern Texas, and parts of California. The small willows, myrtles, a number of dwarf cherries or plums, and many thorny or spiny woody plants are also common in scrub zones. The greatest variety of plants in the scrub zone occurs in the subtropical and tropical areas of Florida.

Pioneer plants do not completely stabilize the dunes and other parts of the coast and the first scrub zone plants that invade among the herbs of the foredunes are usually good dune builders. A general movement of wind-transported material takes place until the scrub vegetation becomes dense. The rate of becoming dense is often slow and depends upon: (1) the frequency of storms and the force and constancy of the strong winds; (2) the number and variety of plants in the scrub zone; and (3) the rate that the soil and other habitat conditions become more moist. Fire is a very important factor because often it has depleted or destroyed scrub zones.

The species of plants composing this scrub zone are more closely related to climatic conditions than are the herbaceous species of the pioneer zone. For example, the pioneer zone American beach grass, Ammophila longiligulata, and the pioneer sea oats, Uniola paniculata, extend from Maine to North Carolina, and from North Carolina to the tip of Florida, respectively. Along this 21 degrees of latitude there are

only a very few plants of the scrub zone that extend over a distance of 7 degrees of latitude. The scrub zone plants near the end of their range are often poorly developed in form, and frequently the plants do not grow rapidly. This partly accounts for the sparse condition of the vegetation of some of these scrub areas.

Forest Type. The tree species present in the scrub zone, such as varieties of the live oak, some palms, many hardwood species, and numerous pines are the forerunners of the forest zone of vegetation. As the soil conditions become more favorable with better humus content and better soil water conditions, many of these trees become of forest size. Other trees enter the area and a forest zone becomes established. This is usually a maritime type of forest, but may be the margin of an interior forest with no trees of distinctly maritime origin.

The forest zone is the climax of the development of vegetation on the broad coastal zone, but it is not always present. Dry coasts such as those of southern Texas and southern California have no forest zone. The vegetation varies from thickets of small, densely grouped trees to open forests of tall trees. The forest may be either coniferous or hardwood, or a mixture of these two. These forests completely stabilize the terrain against all but the most severe disturbances. If the forests are cleared by human activities or destroyed by hurricanes, the areas are difficult to re-establish.

Some of the trees are facultative halophytes and withstand some salt spray and saline soils, but most of them are injured or killed by these conditions. Some forests are wind pruned and have dense and sculptured canopies. They are mostly mesophytic trees which form a mesophytic climax community that is often similar to the interior forests. Some of the conifer forests, especially the pine forests, are a stage of development between the xerophytic, scrub-type vegetation and the mesophytic climax hardwood forests. One of these is the sand-pine scrub forest on Florida dunes.

Some of the coastal areas have only the pioneer type of vegetation which is poorly developed and temporary, especially in the extremely cold and dry climates. Other areas have a scrub zone near the upper beach because erosion has removed the foredunes and the pioneer vegetation. Many regions lack the forest zone, or the forest present is not a maritime forest but rather the seaward or lakeward extension of an interior forest. Dune forests are, however, very prominent along parts of the Great Lakes and the southern part of the Atlantic coast.

The types of natural vegetation are an excellent indicator of the progradation and degradation characteristics of the shores. A long period of time is necessary for the formation of most of the well-developed scrub zones, and an even longer period is necessary for the development of the forest zone. Therefore, if these zones are near a beach it indicates that the area has probably undergone erosional changes since they were developed.

Conversely, a wide pioneer zone with two or more dune ridges covered mainly by herbs indicates recent extension of the coast. A very mixed pattern of vegetation of scrub seaward of herbaceous vegetation and patches of forests in active dune fields usually indicates strong differences in winds and some very erratic changes in the erosion - deposition pattern.

The vegetation also indicates the climatic and soil conditions. The dry coastal regions have a scrub zone which has sparse cover and the plants are usually small, with few or no forest trees. The cold coasts seldom have perennial herbs in the pioneer zone. The warm to hot and humid regions have a dense scrub zone with many species, and often there are well-developed maritime forests.

Each coastal region has a slightly different arrangment of the zones of vegetation, and the species and their relative abundance are different in each zone. The general criteria for a particular type of vegetation or zone are, however, those outlined above, and the management of vegetation, or selecting areas for plantings, should be based on the general characteristics of the three zones and their plants. Shrubs and dwarf trees are often present near the beach, but, even if they are present, the pioneer plants should be used in the plantings because the habitat has been changed by erosion.

The three types of vegetation and the zones they form are usually developed in the sequence indicated in the short descriptions of each zone. The pioneer plants are replaced by the scrub zone plants, and subsequently some scrub vegetation is replaced by forest vegetation. Such sequences are known as plant successions. The course of the development of a succession is a combination of changes in the conditions of the habitat, the population of plants, and the form of growth of the plants. These changes interact upon each other. In development of the coastal region, the most important feature of this succession is the alteration in the physiographic processes of erosion and deposition during the succession. The general change is increased deposition inland from the shore line with final stabilization that allows almost no surface change. The materials that become distinctly sorted are bound together by the plants. Subsequently, these materials become soils as the humus content increases and some slow chemical changes take place among the soil particles.

The population of bare areas by the pioneer plants and the replacement of the pioneer plants by scrub plants are the two important vegetational processes. Nature has used this method for development and it should be imitated and if possible improved to insure the best coastal dune stabilization. . Plantings of species in the wrong zone are usually unsuccessful because the habitat is not suited to them. Plantings of species in climatic regions foreign to their natural habitat may or may not succeed depending upon the adaptability of the individual species.

CLIMATIC REGIONS OF DUNE VEGETATION

The climatic regions in which distinctive types of vegetation and certain important plants occur are not the same as the coastal regions based upon physiographic, geographic, and geologic features. Plants and vegetation conform mainly to conditions of seasonal temperatures and rainfall or other precipitation, and the humidity or dryness of the coastal habitats. The general climatic conditions determine the presence and abundance of most of the species naturally occurring, and the survival and growth of many plants that may be introduced. The soils are mostly sands and are a less critical environmental factor than the climate. Locally, however, the soils range from gravels to fine silts, from strongly alkaline and saline to acid, and from very dry to very wet: therefore, in some areas they determine the local plant communities and the presence or absence of certain species.

The climatic conditions of both temperature and rainfall during the growing season are most important along the northern and central parts of the Atlantic and Pacific coasts and around the shores of the Great Lakes. But in southern regions the higher winter temperatures and the drought conditions are usually more important. Winds, and the salt spray they often carry, are also important, but these cannot be well classified on a regional basis. The incidence of storms, the prevalence of ice, snow, and fog, and some other atmospheric conditions are locally very important, but these cannot be used as general criteria for coastal regions. Therefore, on the general basis of temperature and precipitation the following eight climatic regions are recognized as regions of distinctive plants and vegetation. The regions are delineated in Figure 5.

North Atlantic Region. This region has a shore line about 570 miles long, extending along all the New England coast from the Canadian border to the border of Connecticut and New York, but not including Long Island. It has arctic and cold temperatures, frozen soils, ice, and snow over a long winter season and short, mild summers. Generally abundant precipitation and usually high humidity prevail.

Central Atlantic Region. This region with a shore length of about 520 miles, extending from Long Island and the New York-Connecticut border to Cape Hatteras, North Carolina, has cold temperatures, some ice, snow, and frozen soils but the winters are not severe. This area generally has abundant precipitation and humidity.

Southern Atlantic Region. The extent of this region is from Cape Hatteras, North Carolina to Cape Canaveral, Florida a distance of about 650 miles. It has cool temperatures, rare frosts and very little ice, snow and frozen soils. The winters are mild and short, and there are long periods of summer heat. The region has abundant precipitation, is generally humid, but seasonally dry.

Floridian Region. This region extends from Cape Canaveral, Florida, around the southern Florida Keys area, and northward along the Gulf of

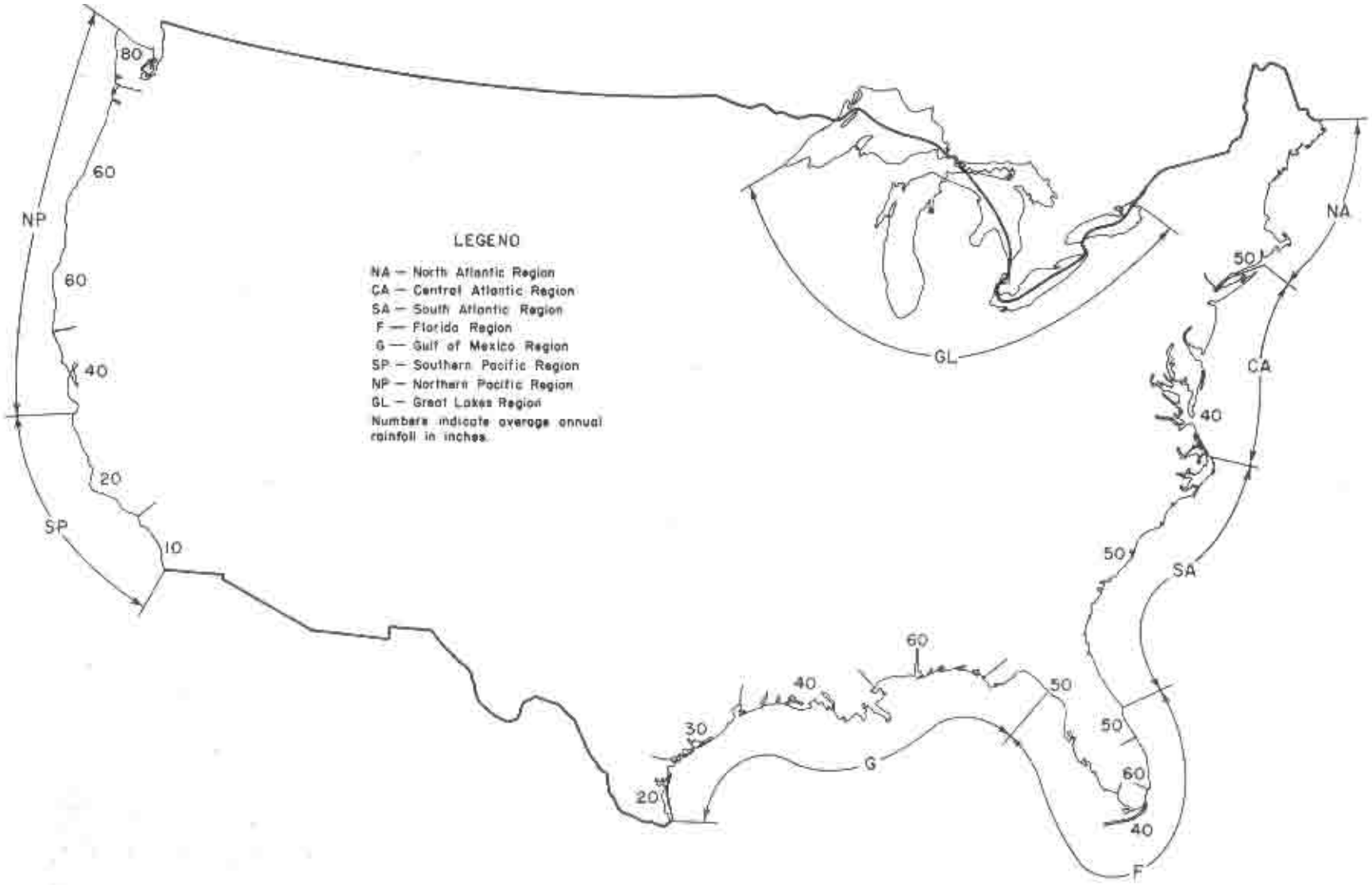


FIGURE 5. CLIMATIC COASTAL REGIONS OF THE UNITED STATES

Mexico to Cedar Key, Florida, a total length of about 750 miles, some sections of which are marshy shores without beaches. It has tropical, subtropical, and warm conditions, with very rare to no frosts and long, warm to hot summers. Rainfall is irregular, varying from abundant to long droughts, with humidity varying from moist to dry.

Gulf of Mexico Region. This subtropical region about 1,600 miles in length extends from Cedar Key, Florida northwest, then west and south to the Mexican border. About 350 miles of this coast, mostly in Louisiana is marsh land without beaches. The region has warm temperate conditions, with frosts occasionally in the northern areas. In southern Texas the winters are short; the summers are long, hot, and often quite dry. Rainfall is irregular, varying from high in Louisiana to rare in southern Texas. Humidity varies from moist to arid.

Southern Pacific Region. The California coast from the Mexican border to the Monterey peninsula, a length of 400 miles, is subtropical with warm temperate conditions. Frosts are rare and summers are long, hot and dry. Rainfall occurs most often in winter and is seldom abundant. The area is dry to very arid.

Northern Pacific Region. From Monterey peninsula, California to the Canadian border, a distance of 900 miles the climate is warm to cool temperate, with some frosts, ice, and snow. Winters are generally long and mild. Precipitation varies from abundant to moderate and the humidity is generally high, especially in the northern part of the area.

Great Lakes Region. This region, extending along some parts of the Great Lakes in the United States, has cold temperate conditions, with long, cold winters, ice and snow, and cool to seasonally hot summers. Here precipitation is moderate and varied, and humidity is moist.

Most of the shores of the Pacific coast are steep and there are less dune areas in this region than along the Atlantic, Floridian, and Gulf of Mexico coasts. The Great Lakes region has very extensive shores, but those with dunes are mainly along Lake Michigan in Michigan and Indiana. Dunes are present along only about 500 miles of the shore line of the Great Lakes in the United States.

There are now only a few hundred miles of coast in all eight regions that have a natural, unaltered vegetation. Several of the small areas of natural vegetation are not typical of the present conditions along the whole region. A few such areas are:

North Atlantic - Gulf of Maine area in Maine; Provincetown area, Cape Cod, Massachusetts.

Central Atlantic - Fire Island on Long Island, New York; Island Beach, New Jersey; Parramore Island, shore of Virginia; some areas of the Outer Banks of North Carolina between the Virginia border and Cape Hatteras

Southern Atlantic - Bogue Banks, North Carolina; Debidue Island, South Carolina; Cumberland Island, Georgia; Fort Clinch State Park, Fernandina, and Mosquito Lagoon area between Daytona Beach and Cape Canaveral, Florida

Floridian - A few partly altered areas on Jupiter Island, Atlantic coast; Key Largo and some others of the Florida Keys; Marco Beach near Cape Romano on the Gulf of Mexico

Gulf of Mexico - The spit partially enclosing Saint Josephs Bay, Florida; Padre and Brazos Islands, southern Texas

The Cape Hatteras National Seashore is the most extensive area preserved and being improved. It is along the Outer Banks of North Carolina. This Federal area, plus all the other Federal and State areas total less than 250 miles of shore line of approximately 4,000 miles of shore along the Atlantic, Floridian, and Gulf of Mexico regions. Many of these areas are used for recreation with hundreds of establishments built on them and thousands of visitors annually; therefore, the vegetation does not remain natural. This results in only a small fraction of the Atlantic and Gulf coasts being expected to maintain the normal vegetation sufficiently intact to have some stabilizing influence.

ZONES OF VEGETATION

The species of plants forming the coastal vegetation of each of the eight regions occur in the three zones; pioneer, scrub, and forest. The number and variety of species usually increase southward along the Atlantic coastal regions until on the Florida Keys area there are numerous species of many plant families. There is also a general decrease in both variety of plants and density of vegetation from regions of abundant precipitation and moist humidity to the regions of low precipitation and aridity, as toward Southern California along the Pacific coast.

Sparse tree growth and a general lack of dense cover of woody plants in all strand zones are characteristic of the North Atlantic region which is partially due to the ice and snow of the long cold winters. Similarly, the lack of precipitation and the long hot summers which are nearly desert conditions produce a sparse vegetation along much of the coasts of middle and southern Texas and the Southern Pacific region.

Strong winds and storms are more prevalent along some regions than others and they have locally altered the density of the vegetation, but in most cases the vegetation has recovered after a few decades. Water, winds, man, and birds bring in exotic species of plants to many areas and some of these plants become well established as part of the flora. Man has been an important agent of introduction of new plants and has promoted naturalization of many exotic species from Europe and other regions. In fact, the planting of exotic species has increased the variety of the flora of some coasts so much that these plants are locally very important.

All the plants and varied types of vegetation of the eight coastal regions cannot be given in detail as such description would be beyond the scope of this paper. However, there are usually a few plants of each region that are characteristic and more abundant than the others and these are noted in detail later. There are some plants that are neither abundant nor characteristic, but are described because they are so much involved in coastal development. Most of the native plants are given in Appendix A and are placed in the vegetative zone in which they most generally occur or are of most advantage for coastal stability. Many more plants are given for some regions than for others due to the number of plants present or observed and described in the botanical literature for each region.

In general, the pioneer zone species are more extensive in their climatic range than plants of the scrub and forest zones. Many of them are grasses and other herbs and some are weeds of ballast and shore debris. Many of them occur on disturbed soils of all coasts. Nearly all of these plants that are useful for plantings are stressed later. Some of the forest zone plants are species common to inland areas as well as coastal zones and the distinctly maritime or coastal ones are difficult to determine. For this reason, only a few of these plants have been listed. The vegetation is not divisible into clearly defined pioneer, scrub, and forest zones in all eight coastal regions because some areas have only poorly developed dune fields. This is reflected in the paucity of species listed for some regions.

The characteristic plants of the three zones of vegetation are nearly all related to the climatic conditions. The plants of the pioneer zone are most related to seasonal differences in temperature and the intensity of winds. Many of them are annual plants with short growing seasons because they occur in the cool and cold temperature regions. The perennial herbs in such regions usually have dormant periods. The grasses and probably some of the other herbs seem to be photoperiodic and are related to the length of the daylight during their growing season. A few of the southern region plants are frost sensitive, and, in general, the scrub zone plants are more sensitive to frost than the pioneer plants.

Many species of the scrub zone plants in the Floridian region, and some in the Southern Atlantic and Gulf regions are sensitive to frost, or are retarded by long periods of low temperatures. The live oaks of scrub form, other scrub oaks, many palms and fibrous leaved plants such as Yucca and Agave, and numerous species of the warm temperate regions extend over a wide range from tropical to nearly cool temperate climatic conditions. One of these is the cabbage palm, Sabal palmetto, which ranges from Cape Hatteras to the southern tip of Florida. These plants of the coastal regions between definitely cool temperate conditions and hot tropical conditions are associated with a variety of subtropical and tropical species in areas south of 30 degrees North latitude. Most of the species of tropical affinities grow south of Cape Canaveral and Cedar Key in Florida, and south of Galveston in Texas.

The forest zone trees are not generally affected by temperature as much as by rainfall conditions. They do not develop well where precipitation is less than 30 inches annually and, therefore, a forest zone is lacking in the most of the arid areas. A number of the evergreen hardwood trees are subtropical and tropical species, while most of the decidous hardwood trees are cool and cold temperature plants. The pines range from those of cold to hot climates, but most of the other conifers, except the red cedar, are cool and cold temperate trees.

AVAILABLE PLANTS IN THE DIFFERENT CLIMATIC REGIONS

Many of the plants of the natural vegetation in each of the eight regions, listed in Appendix A, are available for dune stabilization, particularly for the restoration of the native vegetation of the scrub and forest zones. Reforestation of well-stabilized areas is usually successful if the native species are used. The stock for plantings can be obtained from the surviving forests by obtaining small trees, seedlings, and seeds. Many trees and shrubs can be raised in nurseries, or obtained from commercial sources and from Federal and State agencies. The abundant and dominant species in the scrub and forest zones are generally the most available and are usually the best for permanent stabilization of the inland areas.

In contrast, the pioneer type plants available for dune formation and the first stages of stabilization of the dune fields are not often abundant in the natural vegetation because certain climatic regions lack plants with good dune-building and dune-stabilizing characteristics. Such areas occur along the dry coasts of Texas and California and parts of Florida. Few species occur in some of these areas and these may not grow robustly. The use of plants imported from other regions is then advisable, especially if the exotic plants grow where the soil and climate are similar to those of the region where they are to be used.

Many of the dune areas of most of the three Atlantic coastal regions, the humid parts of the Gulf coast, the Northern Pacific coast, and the Great Lakes shores have numerous grass and shrub species that are good dune builders and stabilizers. Nearly all of them have some favorable characteristic for particular sites, and some can be transplanted successfully if properly dug up, handled, planted, and maintained. The willows, Salix; grasses, Ammophila, Elymus, and Agropyron; and some shrubs, such as species of Prunus and Myrica, have been extensively used. Naturalized exotic grasses, such as the Bermuda grass, Cynodon dactylon; numerous shrubs such as brooms, Cystisus; and junipers, Juniperus, are easy to obtain.

In the Floridian region and parts of the South Atlantic and Gulf regions there are numerous shrubs, palms, and hardwood and conifer trees available in the scrub and forest zones. But some of these, such as the very common and efficient saw palmetto, Serenoa repens, and the live oak, Quercus virginiana; and its varieties, are difficult to dig up and transplant or to raise from seed. Similarly, the common dune-building sea oats,

Uniola paniculata, have proved hard to handle. The cabbage palm, Sabal palmetto; wax myrtle, Myrica cerifera; and the pines are, however, easy to handle and have been extensively used.

Numerous introduced plants, such as the European beach grass, Ammophila arenaria, have been used to aid dune formation and stabilization, and some of these have become so extensively naturalized that they are now part of the natural vegetation. The most numerous of the naturalized exotic species are in the Central Atlantic and Floridian regions where there is much valuable property near resort beaches. The coconut palm, Cocos nucifera, and the Australian pine, Casuarina equisetifolia, are two of the exotic trees most successfully and extensively used in southern Florida. The various shore junipers, Juniperus; some of the roses, Rosa; exotic pines and spruces, Pinus and Picea; and the poplars, Populus, are common in the Central Atlantic region. The list in Appendix A gives the most available native species of all eight of the climatic regions and some of the exotic plants that may be obtained.

The use of native and exotic plants for landscape horticulture around buildings and in gardens and lawns on property near beaches has increased so greatly in recent years that practically every salt-tolerant ground-cover plant, bushy perennial herb, vine, shrub, and tree species or variety have been tried. The numbers and kinds of these plants available for each coastal region vary greatly, with from less than fifty in the Northern Atlantic, Southern Pacific, and dry part of the Gulf region to over one hundred in the Floridian region. The exotic plants used on dunes in southern Florida, as described by Perguson, include seventeen species of pioneer or ground cover types, twenty-eight of the scrub zone areas, and thirty-seven trees. In addition to these there are seventy-two introduced species and varieties and nearly forty species of native plants that have been used. It is therefore impractical to list all available plants used, but those species listed in Appendix A plus information obtained from local nursery men, horticulturists, and botanists should determine those best suited to the area.

In general, the plants most tolerant to salt spray, some soil salinity, some salt water flooding, and those that will withstand high winds are the most useful. Most of these are halophytes or facultative halophytes. Certain families of plants have more genera and species of such plants than others, some of which are: the conifer pine and spruce family, Pinaceae; the monocotyledon families, Palmaceae and Liliaceae; and some grasses, Poaceae; many dicotyledon families, such as Amaranthaceae, Azoaceae, Cactaceae, Compositae, Convolvulaceae, Cruciferae, Ericaeae, Euphorbiaceae, Fagaceae, Lythraceae, Malvaceae, Myricaceae, some of the Papilionaceae legumes, the Portulacaceae, some Rosaceae, some willows and poplars of the Salicaceae, and the Tamaricaceae. Reference to manuals for the coastal species of these families will aid in the search for available plants.

The list of the native and exotic plants available (Appendix A) includes some that have been extensively used and others that have not yet

been extensively used, but which may be very useful if properly handled. It does not include all species of some genera, such as Agropyron, Agave, Elymus, Juniperus, Prunus, Rosa, and Salix, because these generally have so many species appropriate for dune stabilization. The horicultural species and varieties of such genera as Bambusa, Juniperus, Ligustrum, Prunus, and Quercus are also too numerous to list. Reference to such standard listings as in L. H. Bailey's "Hortus", and the "Standardized Plant Names" by Kelsey and Dayton should be made.

The list is not equally representative of all the eight climatic regions because information about plantings in each was not equally available, and also because plants used along the Pacific coast are not well known to the writer. Although some species are found in only one climatic region where some use seems to have been made of the plants, each species or genus may be much more widely used than indicated. Many plants infrequently used or which have proved unsatisfactory are omitted and some of those that are of only local usefulness have been omitted.

The plants listed in Appendix A, and some others that have been less extensively used are not all that are available for use. When the ecological relations of the particular plants are determined, and if a plant has the growth form and abundance characteristics that make it important in the natural plant community it may be used. For example, Panicum amarum, and the several species of morning glories, Ipomoea, the common Spartina patens, and the very extensive sea oats, Uniola paniculata, are a few in the pioneer zone of the Atlantic and Gulf coasts that probably could be used more extensively. Similarly, there are numerous native shrubs, woody vines, succulent plants, palms, and fibrous leaved plants, such as some of the species of Yucca, that are available for use if handling may be made more efficient. The main criteria for usefulness are that they resist salt spray, withstand dry soil conditions, and grow in dense enough groupings to stabilize the sands. The resistance to salt spray is particularly important if they are to be used on the barrier dunes. Such plants should be selected by getting those types which have survived on sites subject to intense salt spray. The same criteria are useful in selecting tree species to be used on the new dunes and near the beaches. It is difficult and expensive to transplant many of these extensively, but those which are suitable may be determined by transplanting a few, and also by observing the growth habits of species in the area that are now nearer the shore than formerly. If a species survives, especially after hurricanes, then it is usually an appropriate one to try in plantings.

Some plants are available for transplanting from one region to another. The absence of a species in a coastal region does not indicate that it will not grow in the region. In fact, many native plants are not extended to the limits of their range because of their lack of migration. Therefore, it is probable that numerous species of all eight regions are available for plantings in similar and adjacent regions, and some of them should be tried. Such tests are described later in connection with

Ammophila breviligulata transplantings in Florida. Many European and a few Asian species have been brought to America to areas in which the climatic conditions differ only slightly from those in which they thrived.

The chief limits to making plants available from one region to another are (1) the limits of frost sensitive species, (2) limits of those that require a dormant rest period of cold winters, (3) limits of those that have certain day length or photoperiod requirements, and (4) the moisture limits of those that thrive in very arid areas. In general, the Floridian species of tropical affinities cannot be used far north of their natural habitat, the Northern Atlantic and Northern Pacific plants probably cannot be planted in the Southern Atlantic and Gulf regions, and most plants of the arid parts of the Gulf and Southern Pacific regions cannot survive in the more humid regions.

METHODS OF ESTABLISHING PLANTINGS

The effectiveness of establishing plantings for the various purposes of dune building and stabilization usually depends upon the methods of doing the following: (a) the selection and procurement of suitable plants which may be obtained without too much difficulty or expense; (b) the arrangement of the plantings which will aid and maintain the development of suitable topographic forms; (c) the methods of planting and care of the plantings which will insure their establishment; and (d) the replenishment of the plantings to promote the final type of vegetation and forms of dunes desired. The management of the extant vegetation often involves some plantings to increase its effectiveness and to stop the deterioration of the vegetation.

Most of the three phases involved in plantings should be planned in conjunction with the overall engineering plans for the coastal region, especially if these plans involve creating or raising dune ridges, artificial nourishment of the beach, and structures on the upper beach or in the dune fields. Plantings are often useful in conjunction with wind screens, such as sand fences. The protection of valuable property from migration of sand may be accomplished in this manner. An arrangement that will decrease wind erosion and maintain the stability of dune formations is desirable. The design of plantings should be related, as much as possible, to the final stabilization of the dunes and the other features present, so that the final forms will hold against all but the most violent storms and most persistent erosion.

Selection of Plants. An important consideration in the selection of nearly all the plants that will probably prove effective in plantings is the adequacy of the supply to insure a sufficiently dense planting to cover the area. The second important consideration is the ease and cost of procuring the plants. Usually there are a number of species that will prove useful and several may be selected from those available. It is becoming more and more difficult to find an abundant supply of desired plants in the natural vegetation that can be removed in quantity for transplanting, and commercial nurseries or the development of a nursery

near the planting site are often necessary. The procurement of seeds for seeding in areas is not usually limited if commercial seeds are used, but if seeds of native plants not stocked by merchants are needed, then the supply must be investigated before plans to use them are made. Transplanting is generally more expensive than seeding and it is sometimes difficult to secure a supply of the desired plants; therefore, the use of seeds should be investigated for every large scale planting.

Many of the plants listed as available in Appendix A are the most suitable, and these should be investigated as to adequacy of supply and ease of procurement. This list does not give all plants that may be useful on a particular site or for some special purpose. The plants used in former plantings, if any, in the region should be investigated thoroughly and the sites should be visited or records examined to determine their success. Plant materials used in former plantings that did not prove successful should be avoided in areas where the conditions are similar.

A desirable characteristic of nearly all early and permanently stabilizing plants is that they withstand some salt spray and some soil salinity. Over a long period almost every coast will be subject to these, often far toward the interior. This tolerance to salinity may be partly determined by the survival of plants in an area where a storm has approached the land from the sea. This tolerance may be determined specifically by testing the range of salinity of the soils where the plants show some deterioration.

The grasses, especially species of Ammophila, Agropyron, Elymus, Andropogon, Festuca and Spartina, have been most extensively used for dune formation and early stabilization; in addition to these there are other genera with similar characteristics which may prove just as useful. Some of the other genera are Cenchrus, Panicum, Paspalum, Poa, and varieties of the Bermuda grass, Cynodon dactylon. There are a large number of other herbs useful for dune formation and early stabilization, a few of which genera are Carex, Euphorbia, Ipomoea, Lathyrus, Lupinus, Oenothera, Polygonum, and Solidago. There are some shrubs, fibrous perennials, semi-shrubs and succulent plants, such as Agave, Iva imbricata, Mesembryanthemum, Opuntia, Prunus, Salix, and Yucca, that have been proved useful. A few of the trees, such as the coconut palm, Cocos nucifera, live oaks, and shore junipers will withstand salinity sufficiently to be planted near the upper beaches.

There are some grasses which have been introduced recently, such as Paspalum notatum and Zoysia tenuifolia, and some other plants, such as species and varieties of Ilex, Hibiscus, Arctostaphylos, and Cupressus, which may be useful and are becoming more available. These new types can be located by contacting agricultural experiment stations, commercial horticulturists, and agronomists. Some grasses and other herbs, however, do not tend to form or hold the dunes in the desired shapes and should not be used even though they possess the desirable traits required and occur abundantly in the natural vegetation of the area. One of these is

the sea oats, Uniola paniculata, of the South Atlantic, Floridian, the Gulf regions, which tend to build and hold dunes which are steep sided.

Plants chosen for use in any zone should not be planted extensively in areas which are very different from those in which they now grow robustly and abundantly. Test plantings, on a small scale, should be made to determine whether the species may be transplanted or seeded without excessive loss or deterioration. Even though the species chosen possesses the required characteristics, transplanting or seeding may prove difficult or may fail because of local conditions.

Selecting and procuring plants for permanent stabilization, improvement of the extant vegetation, or for landscaping property is a more difficult problem because so many more plants are available. The shrubs are generally the most easily handled and survive the best; however, many shrubs that are available do not spread rapidly nor do they withstand salinity, and both characteristics are preferred. Several species and varieties of such genera as Arctostaphylos, Bumelia, Ceanothus, Eleagnus, Ilex, Juniperus, Lonicera, Myrica, Prunus, Quercus, Salix, and Yucca, have proved very useful. The ground cover herbs and low shrubs, such as some clovers, Trifolium; peas, Lathyrus; several grasses, such as St. Augustine, Stenophorum; dune sunflower, Helianthus debilis; and the lupines, Lupinus, have proved effective. Many tree species, especially palms for beautification, have been used to improve the natural vegetation in some regions. Some of these trees, such as the Casuarina, and the bamboos, are used primarily as wind breaks.

The scrub and forest zone plants of the region may furnish most of the planting stock for permanent stabilization and improvement of the vegetation, if the plants can be transplanted or seeded without too much difficulty. In many instances, however, handling native plants is difficult and expensive. The pines and some other conifers that produce seeds abundantly may be grown at nurseries and then transplanted, but the oaks are more difficult to handle in this manner. Species of Myrica are easily transplanted by cuttings and layering and species of Salix are very easily transplanted. In contrast, some of the common dune plants, such as the rosemary, Ceratiola ericoides, and false heather, Hudsonia tomentosa, are very difficult to transplant or raise from seeds and are not recommended for large plantings. Some trees, such as the sand pine, Pinus clausa, are not useful near beaches because they are not salt tolerant even though they are abundant on inland dunes.

In general, the use of seeds for propagation directly onto a site is not as effective as the use of transplants because of the slow rate of growth. In most instances a vegetative cover is desired in a short time. There are, however, some ground cover plants of the early stabilizing type, and some permanent stabilizing plants that can be seeded effectively, such as Festuca grasses, and Trifolium clovers, and some lupines. A number of these usually require some mineral fertilizer to aid their growth, and long dry spells may retard germination of the seeds or kill the young plants.

In the general relations of plants to climate and soils no region has all the different species of plants that are adapted to the habitat conditions, and exotics are therefore often valuable additions to the vegetation. Exotic species often prove more useful and are more easily handled than some of the native trees and shrubs and many of these should be tried more extensively. The exotics are considered to be those from any other climatic region of the same country or from a foreign country, and a great number may be procured by transfer from one region to another. A plant thus to be transplanted should be selected for its obvious preference for several of those soil and other habitat conditions that occur in both places and for their general ability to become acclimatized in new areas. Their adaptability to climate, to soils, and to other factors, should be determined by test plantings before the procurement of large quantities of the exotic plants is made. If there is a wide range of the exotic species in its natural habitat, then the species is more apt to become acclimatized elsewhere.

A general tendency has been to select exotic species from Europe because most of the extensive dune planting has been done there. But, as the number of plantings increase in the United States, the exotic plant materials obtainable here may prove better. A case in point is the genus Ammophila. The European species is A. arenaria, the marram grass, and the American species is A. breviligulata, the beach grass. Plantings in the State of Washington, where both are exotic, have shown that the American species is more suitable. Many other species native to the United States need to be tried in other sections of the country.

Arrangement of Plantings. The arrangement of the plantings, especially for dune formation and early stabilization, should be related to the overall plans for the protection of the coastal region involved. These plans often include structures, grading, and filling. The arrangement of plantings in conjunction with sand fences and other wind screens and on graded or hydraulically filled artificial dunes has been thoroughly tested in a number of areas, especially in the Cape Hatteras National Seashore area of the Outer Banks of North Carolina and on Long Island, New York. A large scale project designed for permanent shore protection and possibly some seaward advancement of the shore line involves many engineering features. The establishment of the proper arrangement and types of dune ridges and dune fields and other features usually also involves a good cover of vegetation as a part of the whole plan. On all these areas the arrangement and position of the plantings should be related to the engineering design. There are, however, many small-scale, short-term plans for shore protection and improvement of coastal areas that cannot be elaborately planned, and plantings on these may be made for temporary benefits.

Plantings on dunes are usually accomplished by using transplanted perennial herbs which spread laterally and upward, and the density and extent of the plantings are related to the way the plants survive and spread. The area should be planted nearly uniformly so as to prevent the

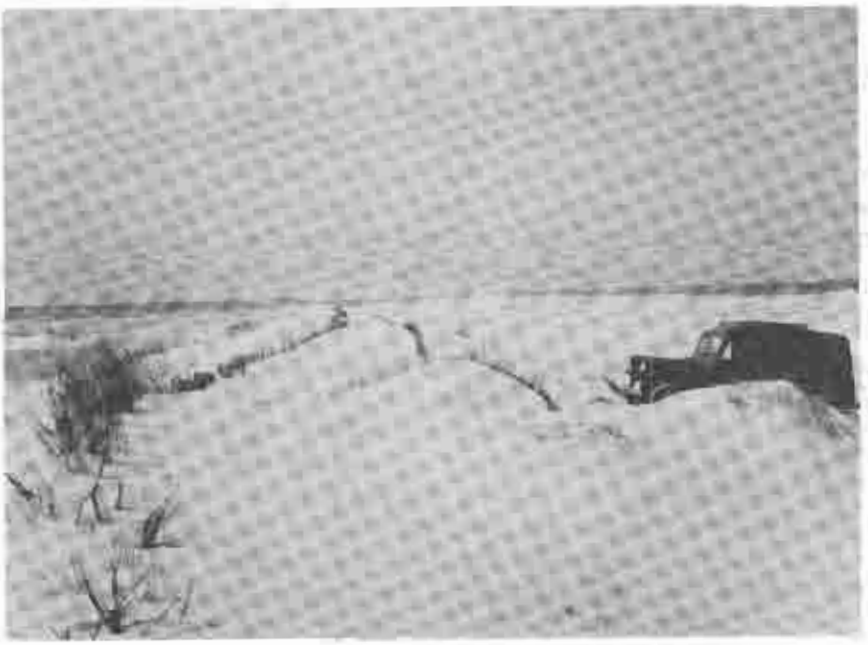
final vegetation from becoming of unequal density at different places, because an irregular cover promotes erosion between areas of greater plant density. Planting in rows is not as good as a random arrangement because rows tend to funnel winds, but rows cannot be avoided at times if planting machinery is used. If sand fences are used to start the dune formation, the design of the fences determines the design of the plantings. The plantings in conjunction with structural installations are described later.

Plantings without sand fences and other devices to aid deposition and stabilization are generally located where some wind deposition is occurring. This limits the position and width of new plants in many places to the drift line and foredune fields of moving sand. The first object is to plant closely enough to assure a sufficient mass of underground parts and tops to cause build-up and stabilization of the sand around the plantings. This usually means a spacing arrangement that is seldom more than 18 inches apart for most grasses, and often less for other plants. The zone of the planting should be as wide as the dune ridge to be developed, so as to assure its formation. If the zone is 200 feet wide, and the plants are set in one foot apart, there will be approximately 43,500 plants per acre.

The plantings for early stabilization are usually on dune fields which have the desired form and position, but not the density of plant cover needed to keep these forms intact. Additional plantings are made on such areas after the form of the dune is nearly fixed. Most such plantings are related to the density of the extant vegetation, and the spacing of the setting in of transplants, or the sowing of seeds, is mainly to cover the bare or sparse areas more densely. Several plantings in sequence during the planting season are usually best so as to insure a nearly uniform plant cover, and often a number of different species of different growth habits are used to create a mixed vegetation. The mixed vegetative cover usually stabilizes better than a vegetation of one abundant species.

Times of Planting. The favorable times of the year for the transplanting and seeding vary a great deal in relation to the climate and the plants used. Most shrubs and trees are transplanted during their dormant period, if any. In cool to cold winter regions, planting during late winter is usually best. Most perennial herbs, especially grasses, take root and begin top growth best if planted during early or late winter, but not mid-winter, in the cool and cold winter climates. Survival percentages of these may be low in areas where winter storms and ice occur because these conditions often bury and uproot the plants. Here the early spring plantings are usually better. Most plantings of seeds should be in the season when germination occurs, in order to prevent the seeds from being blown about or covered too deeply before germination.

The time of planting is also related to the season of rainfall. In warm climate regions, plantings should be accomplished when the soil moisture



Dune reconstruction employing three rows of bush type sand fencing, nine months after installation.

Dune reconstruction employing commercial snow type sand fencing set in zigzag pattern.

Figure 6 Dunes Ready for Pioneer Planting at Cape Hatteras National Seashore Recreational Area, North Carolina. Courtesy of National Park Service.

will be optimum for the region. In all regions plantings should be avoided during the driest and hottest seasons. Plantings on sites of wind-blown sand should avoid the season of high winds, and transplantings should not be made in frozen soil.

Times of Plantings with Sand Fences and on Fills. Plantings in conjunction with sand fences and on artificial dunes and other graded areas should be planned for the best season. This means that construction and grading operations should be timed so that the sites will be in proper condition at the season of planting. The efficient use of labor in planting operations also determines the best time for plantings, especially in cold or hot climates where work is curtailed by adverse climatic conditions. Timing plantings to allow replanting, if the first attempt does not give a sufficiently dense vegetation, is also important and often necessitates both a fall and a spring planting.

After sand fences or other inanimate arresting devices have been installed, planting should begin as soon as deposition fills up to a third to half the height of the fencing. Figure 6 illustrates dunes which are ready for planting. The deposits on the leeward side usually develop first and the first plantings are on them, but if more deposition is on the windward side, that side is planted first. In a pattern of fences, such as the diamond pattern, the first plantings are made where deposition fills in between the panels of fencing and the plantings outside the fencing are made later. The purpose of the first plantings is to fasten deposition in place as soon as practical and to promote as much deposition as possible between the fences, if a pattern is used, so as to form the main body of the dune ridge. Subsequent plantings are made as deposition on the side of the fences not previously planted builds up to about half the height of the fences, and some are made where additional and more rapid deposition will help develop the form of dune desired.

This means that with a single row of fencing, straight or zigzag, there are usually two times of planting, and that with multiple rows in parallel, diamond, and other patterns, there may be three or four different plantings. A general rule for all of these is that the plants should be spaced from 9 to 24 inches apart, in a random, scattered arrangement, as illustrated in Figure 7. A row arrangement may lead to channeling of the winds between the rows of plants, and this may produce more erosion than deposition. If a planting machine is employed rows cannot be avoided; however, some supplementary plantings by hand can be placed between the rows to prevent some of the erosion, especially at the time when such erosion first begins.

Additional plantings along the crest of deposits induced by fences should be made as soon as these deposits cover the top of the fencing, if the plantings already present have not spread to the crest. Some plantings should also be made at or near the base or toe of both the lee and windward sides of the deposits to hold these parts, if former plantings have not spread there. Such base plantings are particularly useful to

Figure 7 Pioneer Grass Plantings at Cape Hatteras National Seashore Recreational Area, North Carolina. Plantings of Ammophila breviligulata spaced about 2 feet apart. Courtesy of National Park Service.

increase the width of the dunes and to prevent steep slopes caused by excessively high crests.

Planting on artificially constructed dunes is usually made at or soon after the time such ridges or mounds have settled into the form desired. It should be done in a scattered arrangement as with sand fences, and plants are inserted 9 to 24 inches apart. The usual form of wind-formed dunes is, however, seldom attained by these mechanically made dunes; therefore plantings should be made that will help change the form toward that of the natural dune. Artificial dunes should be constructed when the plants to be used will grow fast enough to fix the fill in place.

The materials piled into dunes by earth-moving equipment usually have much less uniform texture than those deposited over and near sand fences. It is generally difficult, therefore, to install plants that will grow satisfactorily in all the parts of the piled ridge, especially where coarse gravels and shells are piled. For this reason, the use of plants in conjunction with artificially built dunes of this type is often difficult. The plans should be to build the slopes of as uniform material as possible, but if this is not possible, then plants suited to the different sizes of the fill material should be used. This may involve using a number of different species and making mixed plantings.

Plantings on fills and dune ridges made by hydraulic methods must be made carefully because of the heterogeneous composition of the material. Such fills may have more saline conditions than dunes formed from wind-moved and mechanically placed materials; therefore it may be necessary to wait until after rains have decreased the salinity sufficiently to make the plantings.

The practice along the Outer Banks of North Carolina has proved that it is best to allow dunes constructed by mechanical means to remain without grass plantings until they have reached their natural slopes. If the dunes are planted earlier than this the loss caused by wind will be heavy.

Plantings for Scrub and Forest Zones. Most plantings for permanent stability are arranged over interior parts of the coast and are among existing vegetation. They are used mainly to make the plant cover more dense and to change the vegetation, in some instances, from the herbaceous type to woody type of the scrub and forest zones. The general practice is to plant in the sparsely vegetated and bare areas that have the topographic form that should be maintained for best coastal and interior protection. Some planting is done on areas that have been changed by mechanical grading, so as to stabilize that form. Areas frequently planted are the sand flats behind dune ridges and between them and the second and subsequent dune fields, especially those that flank roads and buildings. The general arrangement of herbs used in such plantings is irregular and they are spaced so as to grow into as dense a ground cover as the soil and water conditions permit. Many flats are inundated occasionally or have high water tables and the commonly used plants are grasses and sedges of wet, saline soils, such as species of Spartina and Salicornia.

When a scrub or forest cover is desired or the plantings are to increase the density of the existing scrub and forest zones the arrangement is related to the mature growth form of the plants and denseness of the vegetation. The degree of density that can be maintained by the particular type of vegetation should be promoted by these plantings. The form of the plant and the density of growth are distinctly different for the forest zone trees compared to the shrubs of the scrub zone, and usually the plantings of the forest trees must be spaced at much wider intervals than the shrub plantings.

So many species of woody plants can be used in these plantings that several different planting arrangements are needed. Usually the pines and some other conifers cannot be placed in the shade of other trees. The heath plants, the sand myrtle, and others, such as the rock roses, form low dense vegetation which should be planted thickly on bare areas rather than between other plants, because they do best in closed stands. A number of trees and shrubs, especially those used for ornamental purposes and some of the large hardwood forest trees, may be planted between other plants to thicken the stands.

The sod-forming grasses and other ground cover plants can be used on some bare areas to hold the top soils in place. A number of the many species and varieties of grasses, peas and other legumes and some composite family plants can be seeded in or tranplanted over bare or sparsely vegetated areas. They should be planted close enough to insure a full coverage of the ground in one season. Some succulent plants, such as the ice box plant, Mesembryanthemum crystallinum, are used as a ground cover in California and Florida.

The arrangement of the plantings of ornamental shrubs, used both for dune stabilization and beautification of private or public beach and dune property, can often be made in groupings, hedge rows and other landscape designs. This is being done increasingly well on property along the residentially developed coasts.

Methods of Planting and Care of the Plantings. The methods of planting by transplanting and by using seeds are diverse and are related to the plants used, the topography, the compactness or looseness and the mobility of the soil materials, and the pattern of arrangement and time of planting. The transplanting method also involves the means of procuring and handling the plants in transit. This is often done within a few days or hours where possible and generally involves one continuous operation. The methods of seeding are mainly by either broadcasting or drilling the seeds into the soil at the right time, depth, and distance apart.

Procuring plants and transplanting them involves digging up as much of the underground parts as practical, some wrapping and bundling, and some pruning of the stems and leaves to reduce water loss during transit. The plants are then set in the soil to the depth that will insure rapid anchorage and sufficient absorption of water and minerals to keep them alive.

The digging is usually done with spades and shovels, and in some cases with plows. In only a few cases can plants be pulled out of the soil. If grasses or other plants with underground stems are to be secured, some care should be taken to dig up at least one joint or node that has roots branching from it. If the plants have a tap root, its main extent should be dug out. As many fibrous lateral and secondary roots should be dug up as is practical on all plants. Usually there is no practical way to retain soil about the roots because the soils are mostly loose sands, but this should be attempted for the larger shrubs and trees because bare rooting is usually not as successful in transplanting as roots with soil.

The planting stock thus obtained needs care immediately. It should be protected from excessive drying or freezing of both the tops and underground parts by bundling the stock together, wetting lightly, and covering with fabrics, plastics or some soil. The stock should not be bundled too tightly nor kept too wet for long periods or some rotting and spoilage will result. Pruning of the tops of some plants often helps to reduce water loss and also helps to stimulate the root and top development after planting.

If the plants are to be transported long distances or kept out of the soil a number of days, they will need protection from water loss and other deterioration. Sometimes this involves rewetting and careful wrapping in bundles that allow some air circulation. General nursery practices for handling and shipping the woody plants should be followed. If the plants are kept near the site for a few days before planting, they can be heeled in.

The planting process is termed sprigging or setting in, and is generally done by hand in holes or furrows 8 inches to 12 inches deep. The setting places are not more than 24 inches apart. Two to four sprigs are set or sprigged in each hole or position in the furrow. The holes and furrows are a random arrangement or staggered rows and files. Backfilling and firming soil around the sprigs should be done within a few minutes after setting in.

The methods of seeding grasses, clovers, and herbs over large areas or using seeds locally to make the vegetation more dense and of better composition are those often used for the particular seeds elsewhere. The methods of using shrubs and tree seeds are, however, almost as varied as the species used and require some knowledge of the way the plant grows. Planting by drilling in the seeds is usually more effective than broadcasting the seeds. Various mechanical drills may be used, especially those adapted to loose sandy soils which can operate over rough terrain.

In general, planting by seeding is not very successful and may be very slow. If time permits, plants should be raised from seeds in a nursery and then transplanted. Greater details on procedures to follow for seeding or transplanting may be obtained from botanical manuals or by consulting local horticulturists or botanists.

Care of the transplanted and seeded plants cannot be intensive because of the expense, except on valuable property. Nearly all seeded and transplanted plants will benefit from watering during dry periods, and many of them will benefit from applications of some mineral fertilizers. Watering, however, cannot usually be done over large areas unless fresh or brackish water is cheap. In some areas both watering and applications of mineral or even organic fertilizers have been found profitable in promoting more rapid and enduring growth. This is particularly true of those seeded areas in which a rapid growth of vegetative cover is needed.

Other protection of the plantings can be effective at nearly every site. This protection is usually against excessive human use of the area until the plants are well established and spreading sufficiently to overcome some of the inevitable human destruction. All planted areas should be protected from fire, grazing and browsing by animals, and in rare cases, from birds roosting and nesting. A few burrowing animals are also harmful. The most useful protections are from fire and human activities.

MANAGEMENT OF THE VEGETATION

Both the extant natural vegetation and the vegetation developed or improved by plantings require some management to insure their maximum usefulness in the preservation of the desirable coastal features. Some of the management was considered under care of the plantings, but more is usually advisable. The basic principle is to preserve those types of vegetation on the sites where they are most likely to maintain the desired topography and improve the area. Preservation of a type of vegetation for a long period of time is not desirable because the coastal zone is subject to a dynamic change through a successional sequence. This succession has been described and is the gradual development of three zones of vegetation from the bare backshore inland. Management should promote this sequence of pioneer, scrub, and forest zones where the space, climate, and soil conditions permit, and if possible, it should in fact speed up the succession.

The forest and scrub zones usually need protection from fire, excessive human disturbance, and harmful animal activities. These often involve no special protection other than the usual fire protection of forest areas and some control of people using the areas for recreation. Clearing and other improvements, building homes, hostelries, and roads are another matter, for these are often done recklessly and without the precaution of preserving as much of the extant scrub and forest vegetation as possible. Grading and clearing for various types of construction close to the beach or on the dunes should be discouraged. Long-term planning for dune and plant maintenance should be enforced in order to provide maximum stability.

In areas where construction has altered the natural conditions, much care and management to improve and restore the vegetation are required. The natural conditions can seldom be restored, but some replanting, thinning, grading, and burning may improve the vegetation. Such active

improvement of sites and vegetation is the best management; however it must be thoroughly planned and executed.

The pioneer zone, which is predominantly a herbaceous type of vegetation, generally needs the most care and management. Grazing and surface fires must be controlled or eliminated. Almost all grading, earth moving and filling should be avoided unless it is planned carefully for protection as well as property improvement. Some of the many human activities, such as digging holes in the sand, running up and down dunes, and breaking and pulling up the plants, should be minimized. To avoid dune field deterioration; the management of some areas may necessitate the prohibition of their use for recreation, especially the excessively eroding areas, so as to allow nature to reform the dune vegetation and permit plantings to prosper.

Management, therefore, amounts to foresight and practical care where possible. This foresight should promote retention of the forms most protective against erosion and the vegetation most apt to promote and hold these forms over a long period. This should include a program to change the vegetation where necessary so that permanent stabilization is realized. Some of this progress can be promoted by the removal of species that crowd the sites, by allowing the growth of or planting better stabilizing and soil-developing species. Thinning of the vegetation may be more effective than complete preservation, which is too often practiced without regard for possible improvement. Plantings of exotic species within natural vegetation are often an improvement in all three zones, and should be tried more extensively.

PERFORMANCE OF DUNE VEGETATION INSTALLATIONS

Plantings and the improvement of extant vegetation have been practiced on coastal areas throughout the world for centuries with notable success in many areas, particularly in Europe during the past few centuries. The records of these installations and their performance in dune formation and stabilization show that most success is due to planning and good methods. A brief summary of the records of some installations in the United States follows. Few records, mostly incomplete, with respect to performance over a period of years after the plantings are available. Usually the maintenance of the plantings and improvement of the natural vegetation were neglected after a few years. On only the Outer Banks of North Carolina has planting and replanting been observed long enough to show the ultimate performance of the installation.

One early installation, started about 1903, was at Cape Cod, Massachusetts. Its purpose was to reclaim areas of drifting sand where forest and scrub vegetation had been depleted. Seven dune ranges were planted to beach grass, Ammophila breviligulata, but no long records of performance are available. At this site the plantings made in the autumn survived better than those made in the spring or late winter for the first few years. Plantings and improvement of extant vegetation over large areas, for which records were obtained, were made during the 1930's on the long barrier

islands of the Outer Banks of North Carolina and along parts of the coast of Oregon. Both of these projects were initiated by the Federal Government and both used Civilian Conservation Corps labor in part. The U. S. National Park Service directed most of the North Carolina Outer Banks installations and it is continuing the current installations in the Cape Hatteras National Seashore area. The older records are incomplete and data on means of plant installation, survival, and cost are meager. The records for the installations along the Outer Banks of North Carolina, particularly for the most recent plantings, are good. The Outer Banks installations were primarily to repair the irregular, eroded dune fields near the beaches. They succeeded well along many miles, as shown in accompanying photographs. The Oregon projects were continuations of attempts, started in 1910 by the U. S. Forest Service, to stabilize migrating dune fields. In 1926-28 another attempt was made by the U. S. Bureau of Plant Industry. The 1930's projects were mostly by the U. S. Soil Conservation Service. The Oregon installations were most extensive on the Clatsop Plain and were to check both shore erosion and the migration of sand toward the interior. No records of the results after the first few years were obtained; however the available records are valuable because they contain data on early survival of different plantings and some estimates of costs.

INSTALLATIONS ON THE OUTER BANKS OF NORTH CAROLINA

After two centuries of grazing by cattle and damage by uncontrolled fires the Outer Banks had become partly denuded of vegetation and much deterioration of the barrier dune ridges near the beaches had occurred. During the period from 1934 to 1940 the National Park Service used sand fences and made plantings on such an extensive and well-designed operation that many barrier dune ridges were developed and stabilized. Large areas of the sand flats were also stabilized. The project used as many as 3,000 men at one time, and most of the plants and mechanical means then known were tried. Plantings in conjunction with various patterns of brush-type sand fences were used. These were very effective in arresting sand and causing the formation of dunes.

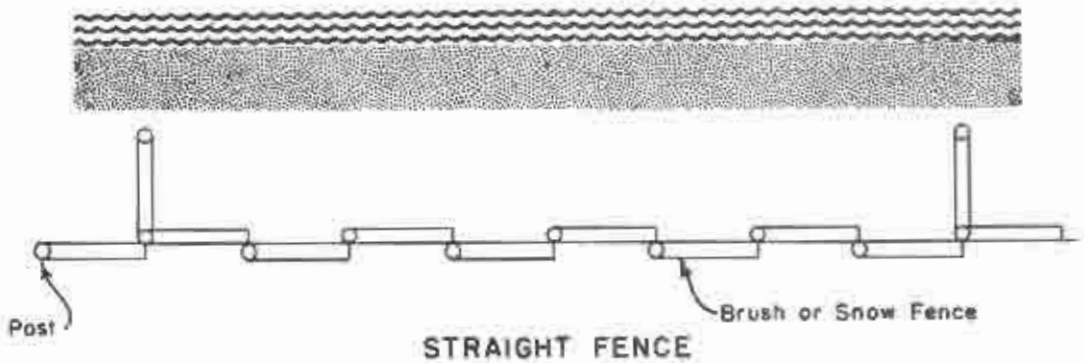
The largest areas of plantings were over the sand flats behind the frontal dunes. These were to stabilize the flats which, because of low elevation, were often flooded. The salt marsh grass or small cordgrass, Spartina patens, was planted on 231 acres, mostly over these flats. The second most abundant plantings, 152 acres, were of beach grass, Ammophila breviligulata. These plantings helped to build and stabilize the dunes formed by the sand fences. Eighteen acres of sea oats, Uniola paniculata, and a few other grasses, such as Panicum amarum, the dune panic grass, and 110 acres of Bermuda grass, Cynodon dactylon, were used. The marsh elder shrub, Iva imbricata, and a few other non-grass plants were also used. All these helped build dunes, but none as effectively as Ammophila. Some plantings were mixtures of two or more species and caused dune formation and rapid stabilization of the flats. Nearly 90 percent of the sea oats and about 65 percent of the beach grass survived. Much smaller percentages of the others survived. The sea oats, however, did not form dunes of the desired shape.

Three arrangements of the brush-type sand fence, shown by Figure 8, were used. The first was a single row or several rows parallel to the beach. The row nearest the beach had short fingers projecting toward the beach, in order to arrest sand moving parallel to the shore. A zigzag arrangement of one or more rows of fencing was also used. Finally, a diamond arrangement was used. This method served best in areas behind the first dune ridge where blowouts had developed and was most effective in building up broad deposits. The first arrangement of fences parallel to the beach was used most widely. Some of them are being installed in the current project.

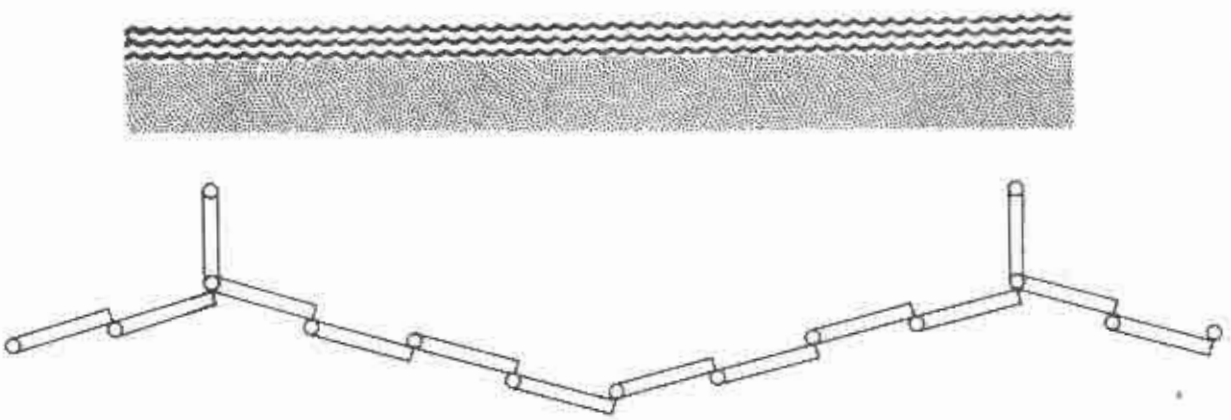
About thirty species of shrubs and trees were planted on the flats and on some of the stable dunes. Some trees were planted on the second or more interior dune fields and in the swales. The common semi-shrub Iva imbricata, and the yaupon holly shrub, Ilex vomitoria, proved to be effective on the developing dunes, but most of the other woody plants survived best on the flats and the older, stabilized dune fields. Some other species planted were, in general order of their percentage of survival: Myrica pennsylvanica, Baccharis halimifolia, Pinus pinaster, Robinia pseudacacia, Acer rubrum, Salix nigra, Cornus florida, and Pinus taeda. However, survival for as much as a decade depended greatly upon local conditions and the relative percentages of survival are not, therefore, very significant. There were some trees, such as the loblolly pine, Pinus taeda, which survived until salt water flooding and salt spray caused by the recent 1955 hurricanes killed them. Live oaks planted on a small scale probably would have survived better if they had been placed more advantageously. Some of the other trees and shrubs tried are Taxodium distichum, Diospyros virginiana, Liquidamber styraciflua, Persea palustris, Juniperus virginiana, Callicarpa americana, and some plums, Prunus spp.

Costs of 1934-1940 Plantings. The costs of these plantings on a unit basis were low by reason of the low labor costs of about one dollar per 6-hour work day. The grass planting cost averaged, for 493.8 acres planted to Ammophila breviligulata, Spartina patens, and Cynodon dactylon, only $36.55 per acre. Planting one acre usually involved 20 to 22 man-days to set in the plants, or about $22 for labor. This compares with the current labor cost, in the same region, of $1 per hour or about $160 per acre. The labor cost is about 60 percent of the total cost, which would result in a total cost of $266 per acre for current plantings. The costs of the tree and shrub plantings are not given on an acre basis, but some estimates may be made. The plants cost about $4.50 per thousand for stock raised in nurseries, plus about $10 per thousand for planting.

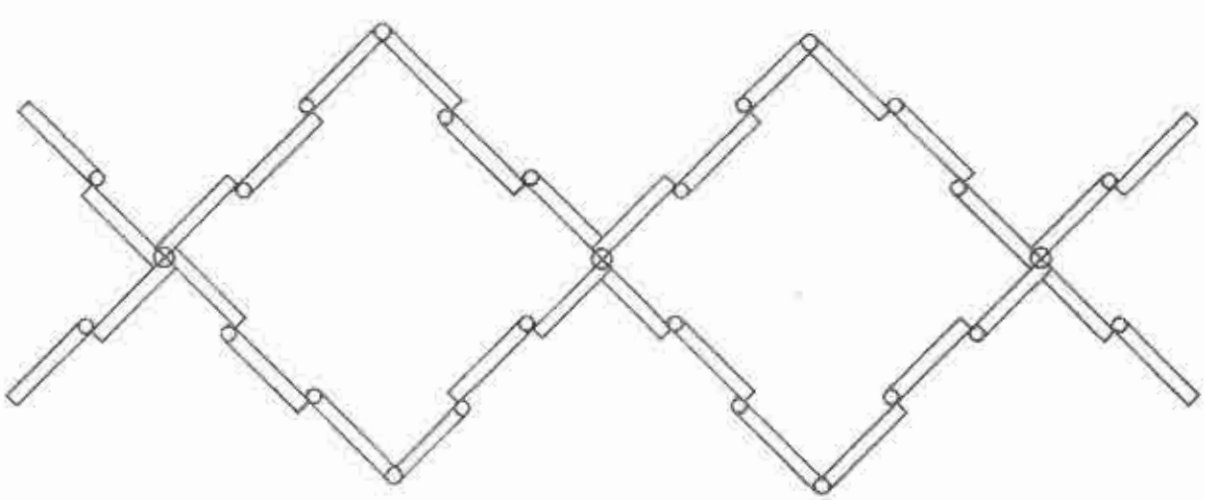
The extensive plantings of 1934-40 proved very successful, especially near Cape Hatteras Lighthouse. The barrier dunes were improved and stabilized, and the beaches were extended seaward naturally along parts of Bodie, Pea, and Hatteras Islands as shown by the upper photograph of Figure 9. Some flats and interior dunes were also improved by the plantings. The areas were stabilized, and some of the wet, low places were built up by increased deposition. The fire and grazing hazards were reduced and



STRAIGHT FENCE



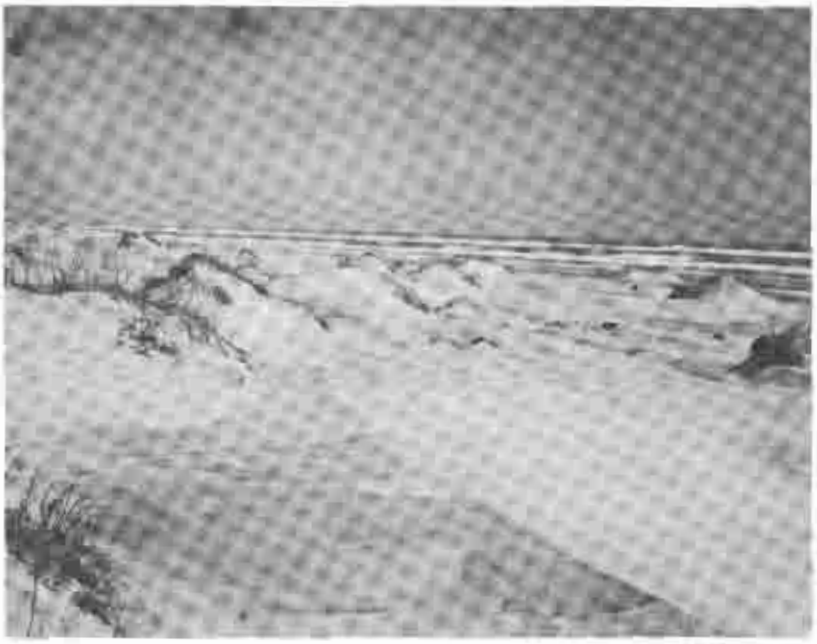
ZIGZAG FENCE



DIAMOND FENCE

FIGURE 8. FENCING DESIGNS USED ON OUTER BANKS, N.C.

Barrier dune built by sand fences and plantings during 1934 - 1940. Area well-stabilized by vegetation.



Remnants of eroded dunes requiring reconstruction and stabilization through use of sand fencing and plantings.

Figure 9 Stabilized and Eroded Dunes at Cape Hatteras National Seashore Recreational Area, North Carolina. Lower photograph courtesy National Park Service.

the native vegetation returned over large areas.

Road building and a great increase in other construction later caused much local deterioration, which soon led to erosion of large gaps and narrow canyons in the barrier dunes. Plantings and sand fences were not used for 15 years to stop this deterioration. Storm waters began to wash across some narrow parts of the barrier islands, especially during the hurricanes, Connie and Ione of August and September 1955. Severe erosion and inundation of large areas occurred. The heavy rains accompanying Ione did much damage. These and other storms destroyed some of the protective dunes, shown by Figure 9, created by the 1934-40 installations. Consequently, a new project of dune building and stabilization was begun in 1956 by the Cape Hatteras National Seashore Recreational Area authorities of the National Park Service and some of the local county agencies.

Current Project. The current project is on a smaller scale than that of the 1934-40 period, but new methods are being used that increase the rate of the installations and probably their efficiency. Dunes are being built with the use of sand fences, as before, and by bulldozing operations. Plantings of grasses are being made on both of these. The dunes thus being made and stabilized are mostly short connecting ridges across gaps in the natural barrier caused by storms. It is planned to restore the continuous barrier dunes and later probably construct dune ridges behind this barrier where space is available. Figure 10 illustrates a part of the current program.

Most of the plantings on the deposits built up by the sand fences could not be made until a few months to a year after the fences were installed because of the slow accumulation of sand. The plantings on the artificial dunes were made a few weeks after their construction. Nearly all of the plantings have been made on the interior or landward slope of the dune. In some places sand fences were put in two or more rows and plantings made between them as well as on the inner slope. The plantings were mostly of the beach grass, Ammophila breviligulata, with the cordgrass, Spartina patens used on some sites. Only a few individuals of other species were used. About 80 percent of the beach grass planted during 1956-57 is surviving; however on some slopes where erosion is severe, the spring growth is less and replanting probably will be necessary.

Costs of Current Project. The costs of current installations, given in Table 2, are only estimates because some of the equipment and overhead cost items cannot be determined accurately until the project is nearer completion.

Brush type sand fencing shortly after installation.

Mechanically constructed dune ridge stabilized by plantings situated in wide gaps through dunes.

Figure 10 Work Under Current Program at Cape Hatteras National Seashore Recreational Area, North Carolina. Lower photograph courtesy of National Park Service.

TABLE 2

APPROXIMATE COSTS OF CURRENT CAPE HATTERAS NATIONAL SEASHORE INSTALLATIONS

Item	Operation	Costs ($)
Brush fence	Fabrication and installation	.40 per lin. ft.
Snow fence	Purchase and installation	.30 " " "
Dune	Bulldozer construction	.10 to .25 per cu. yd.
Dune	Sand fence construction and maintenance (including cost of fencing)	.50 per lin. ft.
Plants	Planting	275 per acre

These approximate costs indicate that an installation of two rows of brush sand fencing with planting 50 feet wide on the inner slope costs approximately $130 per 100 feet of dune. In contrast, the cost is $1,360 per 100 feet of a bulldozed dune of the dimensions given above. Most of the artificially constructed dunes are not built with an 80-foot base, and their cost is less than that given above. In spite of the greater cost, however, the artificial dunes are preferable to the dunes formed by sand fences across those gaps that must be closed rapidly. In some areas the fences do not accumulate sand rapidly enough to form the high ridge necessary for good protection.

The artificial dunes have one serious difficulty for plantings. The source of sand is often the upper beach area and the fill is composed of a mixture of sands, gravel, and shells. This material is not uniform and in some of the ridges is too coarse to hold sufficient water for the plants to establish themselves. Most of the buildup around sand fences, in contrast, is a uniform textured fine sand, and the plantings survive better on them than on the artificial dunes.

OREGON PLANTINGS

These extensive plantings were for the dual purpose of shore protection by building and stabilizing dunes and stabilizing interior dune and sand flat areas to prevent migration toward the interior. Most of the large scale plantings were done between 1934 and 1940. The largest areas planted were near Coos Bay and on the Clatsop Plain. The initial plantings were on shore areas, and were to build and stabilize the barrier dune areas. Later plantings of many types of stabilizing plants were made on the dunes and over interior areas where sand was migrating. Over fifty species of plants were used. Seeding methods were also used.

The plants used to form and stabilize the barrier dunes were mostly Ammophila breviligulata with some Ammophila arenaria. The former grass proved better. Elymus mollis was also used, but it did not survive well because the plants must be completely dormant at transplanting time. The secondary plantings were mainly of commercial seeds and a few native seeds

gathered locally. They include Lupinus littoralis, Lathyrus japonicus, Poa micrantha, and Festuca rubra. Some of the clovers, Trifolium, were also successfully started from seeds. They were used only on the permanently stabilized, interior areas.

Numerous shrubs, trees, and woody vines were transplanted, among which Lupinus arboreus, Rosa nutkana, Salix hookeriana, and Picea sitchensis were the best native species. Some of the exotic species used successfully were the Scotch broom, Cytisus scoparius, the black alder, Alnus glutinosa, and four pines, Pinus pinaster, P. sylvestris, P. pungens, and P. nigra. Some of these woody plants were used as ornamental plants to improve the forest and scrub zones.

Costs. The approximate costs of several of the component operations of this project are given in Table 3.

TABLE 3

APPROXIMATE COSTS OF OREGON INSTALLATIONS

Item	Costs per acre
	$
Grasses	25
Seeds (commercial)	1 to 21
Seeds (natural)	7 to 18
Trees (commercial and natural including costs of trees)	30 to 200
Grass planting at 12-inch intervals	50 to 100
Grass planting at 18-inch intervals	40 to 60
Fertilizer (40 pounds per acre)	6 to 8
Management and Maintenance	5 to 20

LONG ISLAND, NEW YORK, INSTALLATIONS

Installations along the south shore of Long Island have recently been made by a number of New York State agencies. Hydraulic fill was used to construct a barrier dune and beach grass was planted to stabilize the fills. The plantings were done in irregular pattern 15 to 18 inches apart, between September 15 and May 15. Such hydraulic fill often contains more salt than Ammophila breviligulata will tolerate; therefore the plants are set in only after tests have shown that the fill salinity is not greater than the salinity of the soil of the site from which the plants were taken. This condition is usually reached after rains have diluted and leached the salt from the fill.

The hydraulic fill dune ridges thus constructed had top elevations of about 18 feet above mean sea level. The top width was 50 feet and the base varied from 250 to 300 feet in width. Both slopes were 1 on 15. These gently sloping, well-constructed ridges have proved adequate for protection. Snow fences were used for dune buildup at times, the zigzag pattern proving best for maximum sand entrapment. Deposition of sand occurred during the time of the northwestern winter winds.

Specifications included not only the first plantings but also care and replanting. Instructions for digging, handling, and planting stressed subdividing the clusters or clumps of grass, which were dug from areas near the fill, and keeping the bundles of plants moist or heeled in until planted. The planting or sprigging in was to 8 to 10 inches deep and usually four stems were planted in each placing. Almost all planting was done by hand with the use of a dibble type spade. The soil was firmed or backfilled about the plants. Planting was accomplished over the entire fill.

Ornamental shrubs and trees and some other plants have been planted in the same area, usually on more interior dune and upland parts, with success. Plants which withstand winds, salt spray and other coastal conditions were used. Ten species commonly used were: Myrica pennsylvanica, Eleagnus angustifolia, Prunus maritima, Rosa rugosa, Ilex crenata, Ligustrum ibota, Populus alba, Pyracantha coccine, Pinus thunbergi, and Juniperus virginiana. The high value of the residential and recreational property of this region assures the continued use of plantings for dune stabilization.

The costs, as given by the two agencies involved in the project, were $400 and $500 per acre. The larger figure is based on a labor cost of $2.60 per hour.

TEST PLANTINGS IN FLORIDA

Plantings of beach grass, Ammophila breviligulata, were made in three distinctly different areas in Florida during 1956 and 1957 to test the survival and growth of this plant far south from its usual climatic range. Such plantings are primarily to determine if a species that has proved useful elsewhere can be used in a coastal region distinctly different from the one in which it occurs. The plants were obtained from the Outer Banks of North Carolina, which is over 10 degrees of latitude north of the southernmost place of planting at Jupiter Island on the Atlantic coast near Palm Beach. The two other plantings were north of Jacksonville, near Fernandina fronting the Atlantic Ocean and near Panama City on the Gulf of Mexico. Thus plants from the Central Atlantic Region are being tested in three coastal climatic regions, the Southern Atlantic, Floridian, and Gulf of Mexico.

Plantings were made in December near Fernandina and Panama City, and in March and April on Jupiter Island and near Fernandina. The records of survival and growth are to late April and May 1957. This is too short a time to determine the eventual survival during the hot summer months, but long enough to determine that the December plantings had started active growth. Later, more extensive plantings of a number of species using transplants and seeds are to be tested near the same sites for the purpose of determining the survival and growth after transfer to a distinctly different region.

Two areas were planted on December 20, 1956 at St. Andrews State Park near Panama City. The first was on and between dunes in the pioneer zone where sand was moving. Three rows of plants were set in transverse to the prevailing wind, and three rows were parallel to the prevailing wind. The other planting was on a level area near buildings where little or no sand movement occurred. Of 522 plants placed in the first area only 233 survived to May 15, 1957, partly because parts of the rows were covered too deeply by sand. Some of these buried plants may grow to the surface later. Of 286 placings of plants in the second area, 266 survived to May 15. This area was watered during dry spells. This area is to test the growth of Ammophila in a nursery to furnish stock for later transplanting. Survival in the first area was about 44 percent and in the second about 93 percent.

Near Fernandina Beach, in Fort Clinch State Park, plantings were made in a low pioneer dune area near the upper beach on December 22 and April 2. Of the 875 plants set in December, 609 or 69 percent, had survived to April 28. About 85 of the 112 planted on April 2 had survived. These plants were surviving better and growing more rapidly than those near Panama City, probably because of greater stability of the sand. The two areas had nearly the same temperatures and rainfall during this period.

Two small plantings were made on Jupiter Island, near Palm Beach on March 28, but one of these areas was later dug up so that data on only one small planting of 112 placings are available. Of the 112 placings, 80 were alive on May 25 and some were making good growth. This planting was late in the season for this climate and a low survival is probable.

If the survival and growth percentages of these three test plantings are high enough to indicate that larger plantings could be made with expectations of getting enough cover of Ammophila to serve for dune buildup and stabilization, then this plant might be used in the same manner now extensively used on natural and artificial dunes elsewhere. It is preferable to some of the native dune-building plants, such as the sea oats, because it builds and holds dunes in a more even shape with less steep sides. This is the manner in which exotic species may be tested to determine their usefulness.

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APPENDIX A

PLANTS OF THE EAST COASTAL REGIONS

The following list of plants is not intended to be a complete list of all plants found along the coasts of the United States. The intent, rather, is to list all plants which are either economically important or which are greatly involved in coastal changes and stability. Many of the species listed are exotic and may become important after trial in a coastal region. All species of some genera are not listed because these genera have so many species which are appropriate. Information should be obtained from local horticulturists and botanists to determine those species best suited to a specific area.

The table is an alphabetical list of the species by scientific name. The local or common names are included for convenience. All eight climatic regions are not equally represented, however, because some species grow in the warm moist climates and because plants used along the Pacific coast are not as well known to the writer. The remainder of the table indicates the proper region and zone for each species.

SYMBOLS AND ABBREVIATIONS

Climatic Regions

NA - North Atlantic
CA - Central Atlantic
SA - South Atlantic
F - Floridian
G - Gulf of Mexico
SP - South Pacific
NP - North Pacific
GL - Great Lakes

A - Species present in given zone and region not recommended for use in that zone and region

P - Species present in given zone and region but not recommended for transplanting in that zone and region

C - Exotic species which is recommended for use in a given zone and region

1 through 10 - Indicates prevalence of a species in a given zone and coastal region such that 1 is the most abundant or dominant species present in that zone and region

11 - Indicates that presence of a species which is not among the ten most prevalent species in the given zone and coastal region

* - Recommended for use on experimental basis. Zone and region of use not determined at present.

SCIENTIFIC NAME	COMMON NAME	PIONEER ZONE								SCRUB ZONE								FOREST ZONE							
		NA	CA	SA	F	G	SP	NP	GL	NA	CA	SA	F	G	SP	NP	GL	NA	CA	SA	F	G	SP	NP	GL
Abronia fragrans														B11											
Abronia latifolia	yellow sand verbena							A-1																	
Abronia maritima	red sand verbena						A-1																		
Acacia farnesiana	sweet acacia												B11												
Acacia latifolia	wattle													C											
Acacia wrightii	catclaw													B11											
Acanthocereus floridanus	gilldoe cactus												B11												
Acanthocereus pentagonus	triangle cactus													B11											
Acer rubrum	red maple																		B11						
Acer saccharum	sugar maple																	B11	B11						B11
Achyranthes maritima	chaff flower			B11	B11																				
Acrostichum floridanum	swamp fern													C											
Agave americana	century plant			C	C	C	C						C	C											
Agave sisalana	sisal century plant			C	C	C	C					A-11	A-6	A-6	C										
Agropyron dasystachyum	hairy wild wheat	C						A-1	C																
Agropyron repens	wild wheat	B11																							
Agropyron repens	witch grass-couch grass	C	A-9						A11																
Agrostemma spp.	wild wheats	A11	C					C	C																
Alnus glutinosa	alder									C															
Alnus maritima	seaside alder										B-9														
Alnus arborescens	hush alder												C		C										
Amelanchier canadensis										B11								B11							
Ammophila arenicola	sand bigreed					B11																			
Amsonia ciliata	sandhill willow	B11	B11					C																	
Amsonia tomentosa	Beach grass	A-1	A-1	C				C	A-1																
Amyris elemifera	sea amyris												B11								B11				
Amyris texana	Texas amyris													B11											
Andropogon furcatus	big blue stem grass								B11																
Andropogon glomeratus	beardgrass				B11																				
Andropogon hirtiflorus	beardgrass				B11																				
Andropogon littoralis	coastal beardgrass			A-10		A-10																			
Andropogon scoparius littoralis	coastal broomgrass			B11								B11													

SCIENTIFIC NAME	COMMON NAME	PIONEER ZONE								SCRUB ZONE								FOREST ZONE							
		NA	CA	SA	F	G	SP	NP	GL	NA	CA	SA	F	G	SP	NP	GL	NA	CA	SA	F	G	SP	NP	GL
Andropogon scoparius	beardgrass	B-7	B-7						B11																
Andropogon virginicus	broom sedge				B11																				
Anemone cylindrica	thimble weed								B11																
Antennaria spp.	everlastings				B11	B11																			
Aralia spinosa	prickly ash											B11													
Arbutus menziesii	arbutus																							B-1	
Arctostaphylos manzanita	Manzanita																			C					
Arctostaphylos pumila	dune manzanita															B11									
Arctostaphylos spp.																								A-5	
Arctostaphylos tomentosa	shaggy bark manzanita															B11								B11	
Arctostaphylos uva-ursi	madrona									A-2	C					C	B11								A-6
Arenaria peploides	sea sandwort	A11						C																	
Arenaria spp.	sandworts	C	C					C																	
Aristida gyrans	three-awned grass			B11		B11																			
Aristida purpurascens	three-awned grass								B11																
Artemisia caudata	wormwood	C	A11						B11																
Artemisia pychnocephala	sand sagebrush						B11								B11	B11									
Artemisia spp.	wormwood		C						C																
Artemisia stelleriana	dusty miller	B-4	B11						B11																
Asclepias tuberosa	butterflyweed						B11																		
Aster tortifolius	desert aster						B11																		
Atriplex acanthocarpa	orach					B11																			
Atriplex arenaria	seabeach orach	B-2	A-7	B-8	B11	B11																			
Atriplex canescens	saltbush														B11										
Atriplex cristata	orach				B11																				
Atriplex littoralis	orach								B-4																
Atriplex patula	orach	B11	B11																						
Atriplex spp.*	orach																								
Avicennia nitida	black mangrove												B11								B11				
Baccharis angustifolia	groundsel bush											B11	B11	B11											
Baccharis halimifolia	sea-myrtle, fingerling										A-4	A-5	A11	A11											
Baccharis pilularis	fingerling						C																		
Baccharis spp.*	groundsel																								
Bambusa spp.	bamboo											C	C	C											
Batis maritima	saltwort				B11								B11												
Befaria racemosa	tar flower											B11		B11											
Berchemia scandens	supple-Jack											B11		B11											
Betula papyrifera	paper birch									B11								B11							
Betula populifolia	gray birch																	B11							
Boerhaavia scandens	four o'clock				B11																				
Borrichia arborescens	sea oxeye											B11	B11												
Borrichia frutescens	sea ox-eye				B11							B11													
Bucida buceras	ox horn																				B11				
Bumelia angustifolia	buckthorn											C	A11	C											
Bumelia celastrina	saffron plum													B11							B11				
Bumelia lanuginosa	gum bumelia											B11		B11											
Bumelia reclinata	buckthorn												B11												
Bumelia spp.	buckthorns											B-4		B-4											
Bumelia tenax	tough bumelia											B11	A11												
Bursera simaruba	gumbo-limbo																				B11				
Byrsonima lucida	locust berry												B11												
Cakile edentula	sea rocket	A-2	A-6	A-6	B11	C	A-7	A11	A-2																
Cakile lanceolata	sea rocket				B11																				

SCIENTIFIC NAME	COMMON NAME	PIONEER ZONE								SCRUB ZONE								FOREST ZONE							
		NA	CA	SA	F	G	SP	NP	GL	NA	CA	SA	F	G	SP	NP	GL	NA	CA	SA	F	G	SP	NP	GL
Cakile spp.*	sea rocket																								
Calamovilfa longifolia	dune grass					B11			A-2																
Callicarpa americana	beauty berry											B11		B11											
Calocarpum [illegible]	butterfly variona						A-2																		
Canavalia lineata	sea bean, bay bean			B11	B11	B11																			
Capparis cynophallophora	hurricane capper												B11												
Capparis jamaicensis	Jamaica capper												B11												
Carex arenaria	sedge	B11																							
Carex kobomugi	Japanese sedge		D																						
Carex silicea	sand sedge	B-10																							
Carya floridana	Florida hickory																		B11	B11	B11	B11			
Carya glabra megacarpa	pignut hickory																		B11	B11	B11	B11			B11
Carya ovata	shag-bark hickory																								B11
Cassia aspera	partridge pea				B11																				
Cassia brachiata	sensitive pea			B11		B11																			
Cassia clusiifolia	[illegible] apple												B11												
Cassia fasciculata	dune senna						B11																		
Castanea pumila	chinquapin																		B11						
Castilleja littoralis	coastal paint brush							B-6																	
Casuarina equisetifolia	Australian pine																				B11	B11			
Ceanothus dentatus	dwarf ceanothus														A-2										
Ceanothus spp.*	ceanothus																								
Celtis occidentalis	hackberry																	B11							
Celtis pallida	hackberry													B11											
Celtis pumila	hackberry																B11								
Cenchrus pauciflorus	sand-spur			B11	B11	B11																			
Cenchrus tribuloides	sand-spur			B11		B11																			
Ceratiola ericoides	rosemary											B11	B11	B11											
Cereus spp.*	cereus cacti																								
Chenopodium album	pigweed	B11	B11																						
Chloris glauca	finger grass				B11																				
Chloris petraea	finger grass			B11	B11	B11																			
Chrysobalanus icaco	coco-plum												B11												
Chrysoma pauciflosculosa	woody goldenrod					B11																			
Chrysopsis graminifolia	golden aster				B11																				
Chrysopsis mariana	golden aster					B11																			
Cirsium pitcheri	beach thistle								B11																
Cirsium, spp.	common thistle	B11				B11																			
Citharexylum fruticosum	fiddlewood																				B11				
Citharexylum sp.													B11												
Citrus spp.*	citrus																								
Clethra alnifolia											B11														
Cnidoscolus stimulosus	nettle			B11		B11																			
Coccoloba laurifolia	pigeon-plum												B11												
Coccoloba uvifera	sea grape												A-2												
Coccothrinax argentata	silver palm												B11												
Cocos nucifera	coconut palm				C								B11	C											
Colubrina arborescens	coffee colubrina																				B11				
Conocarpus erecta	buttonwood												B11												
Conradina grandiflora	shrub mint											B11		B11											
Cordia sebestena	geiger bush												B11												
Coreopsis gigantea	tree coreopsis														B11										
Coreopsis maritima	sea coreopsis					C									B11										

SCIENTIFIC NAME	COMMON NAME	PIONEER ZONE								SCRUB ZONE								FOREST ZONE							
		NA	CA	SA	F	G	SP	NP	GL	NA	CA	SA	F	G	SP	NP	GL	NA	CA	SA	F	G	SP	NP	GL
Corispermum hyssopifolium	bugseed-tumbleweed		B11						A11																
Cornus florida	flowering dogwood									B11	B11														
Cornus nuttalli	western dogwood																							B-8	
Cornus stolonifera	red osier																B11								
Corylus americana	hazelnut										B11														
Crataegus crus-galli	hawthorn																B11								
Crinum spp.	swamp lily				A11	A11																			
Crotalaria spp.*	crotalarias																								
Croton argyranthemus	croton			B11		B11																			
Croton linearis	narrowleaf croton			A11	A11	A11																			
Croton fergusoni	croton				B11																				
Croton punctatus	silver-leaf croton			A11	A11	A11																			
Croton spp.	croton			A11																					
Cupressus goveniana	Gowen cypress														B11										
Cupressus macrocarpa	Monterey cypress														A11								A11	A11	
Cupressus spp.	cypresses										C														
Cynodon dactylon	Bermuda grass			A11	A11	A11	C																		
Cyperus brunneus	sedge				B11																				
Cyperus lecontei	coco-grass			B11		B11																			
Cyrilla racemiflora	titi													B11											
Cytisus spp.	brooms										C					C	C								
Dalbergia brownei	rosewood												C												
Dalbergia ecastophyllum	shore bean shrub												B11												
Digitaria filiformis	finger grass		C	C																					
Digitaria sanguinalis	finger grass			B11	B11																				
Dipholis salicifolia	willow bustic																				B11				
Distichlis spicata	spike grass			B11		B11																			
Drypetes lateriflora	Guiana plum												B11							B11					
Dudleya pulverulenta	chalk lettuce						A11																		
Echinocystis fabacea	wild cucumber						B11	B11																	
Elaeagnus angustifolia													C												
Elaeagnus argentata											C					C	C								
Elaeagnus spp.*																									
Elymus arenarius	sea lymegrass	A11	A11						C																
Elymus arenicola	sea rye grass							B11																	
Elymus canadensis	wild rye	A-6	A11						B-7																
Elymus flavescens	yellow rye grass							B-8																	
Elymus mollis	dune grass							B11																	
Elymus robustus	wild rye								B11																
Elymus spp.*	rye grass																								
Encelia californica	bush sunflower														B11	C									
Equisetum arvense	horsetail		B11																						
Eragrostis ambalis	love-grass				B11																				
Eragrostis hypnoides*	love-grass																								
Eragrostis oxylepis	love-grass					B11																			
Eremochloa spp.*	centipede grass																								
Erica spp.	heaths									C	C					C	C								
Erica tetralix	heath									B11															
Ericameria ericoides	heath composite														B11										
Eriogonum latifolium	buckwheat							B11																	
Erithalis fruticosa	dune berry												B11												
Ernodea littoralis	coastal ernodea												A11												
Eryngium maritimum	sea holly		C	C																					

SCIENTIFIC NAME	COMMON NAME	PIONEER ZONE								SCRUB ZONE								FOREST ZONE							
		NA	CA	SA	F	G	SP	NP	GL	NA	CA	SA	F	G	SP	NP	GL	NA	CA	SA	F	G	SP	NP	GL
Erysimum capitatum	wall flower						B11	B11																	
Erythrina arborea	coral bean												B11												
Escallonia rosea	escallonia														A11	C									
Eschscholzia californica	California poppy						B11	B11																	
Eucalyptus spp.													C		C	C									
Eucalyptus umbellata	horn cap												C	C											
Eugenia axillaris	white stopper												A11								A11				
Eugenia buxifolia	box leaf stopper												C												
Eugenia dicrana	redberry stopper																				B11				
Eugenia myrtoides	box leaf stopper												B11								B11				
Eugenia spp.													B-T												
Euonymus spp.*																									
Euphorbia buxifolia	shrub spurge			C	A11																				
Euphorbia ingallsii	creeping spurge				B11	B11																			
Euphorbia innocua	spurge					B11																			
Euphorbia polygonifolia	seaside spurge	B11	B11						B11																
Euphorbia spp.*	spurges																								
Exostema caribaeum	princewood																				B11				
Fatsia japonica	aralia														C	C									
Festuca arenaria	sand fescue		C																						
Festuca rubra	red fescue	A11						C																	
Ficus aurea	strangler fig																				B11				
Ficus laevigata	wild fig																				B11				
Fimbristylis castanea	sand rush			A11	A11	A-9																			
Fimbristylis spp.*	rushes																								
Forestiera porulosa	Florida privet											C	A11	C											
Fragaria chiloensis	sand strawberry						C	A-3																	
Frankenia grandifolia	yerba reuma														B11										
Franseria chamissonis	sand ambrosia						A-3	A11																	
Fraxinus nigra	black ash																	B11	B11						
Galactia canescens	milk pea					B11																			
Gaultheria shallon	salal															C									
Gaylussacia baccata	black huckleberry									A11	A11						B11								
Geobalanus oblongifolius	gopher apple												B11												
Gossypium religiosum	tree cotton												B11												
Guaiacum sanctum	lignum vitae																				B11				
Guilandina bonduc	nicker vine												B11												
Guilandina crista	nicker vine												B11												
Gymnanthes lucida	crabwood												B11								B11				
Hamamelis virginiana	witch-hazel											B11						B11	B11						
Haplopappus canus	golden bush													B11											
Harrisia spp.	prickly apples cacti												B11												
Helianthemum scoparium	rush-rose													B11											
Helianthemum spp.*	sun roses																								
Helianthus debilis	dune sunflower			A11	A11	A11																			
Heliotropium convolvulaceum	heliotrope					B11																			
Heliotropium curassavicum	heliotrope				B11																				
Heliotropium parviflorum	dune heliotrope			B11		B11																			
Heterotheca subaxillaris	golden aster					B11																			
Hibiscus tiliaceus	sea hibiscus																				A11				
Hippomane mancinella	manchineel																				B11				
Holcus lanatus	velvet grass	C						C																	
Hudsonia tomentosa	false heather									A-T	A11						A11								

SCIENTIFIC NAME	COMMON NAME	PIONEER ZONE								SCRUB ZONE								FOREST ZONE							
		NA	CA	SA	F	G	SP	NP	SL	NA	CA	SA	F	G	SP	NP	SL	NA	CA	SA	F	G	SP	NP	SL
Hydrangia arborescens	shrub hydrangia										C														
Hydrocotyle bonariensis	seaside pennywort			A11	C	A-5																			
Hymenocallis keyensis	key spider-lily				A11																				
Hymenocallis palmeri	dune spider-lily			B11																					
Hymenocallis spp.					B11																				
Hypericum aspalathoides	sand cypress			B11		B11																			
Hypericum fasciculatum	sand cypress											B11		B11											
Icacorea paniculata	marlberry												B11												
Ilex glabra	gallberry										B11	B-9													
Ilex opaca	American holly									B11	B11	B11		B11					B11	B11		B11			
Ilex verticillata	winterberry									B-9	B-7														
Ilex vomitoria	yaupon											B-2	B11	B-3											
Ipomoea pes-caprae	railroad vine			A11	A-6	A-6																			
Ipomoea spp.	morning-glory			A-5																					
Ipomoea stolonifera	beach morning-glory			B11	A11	A11																			
Iva imbricata	marsh-elder	B-5	B-5	A-6	A-3	A-3					B11	A11	A11	A11											
Jacquinia keyensis	joewood												B11												
Juncus longistylis	coastal rush							B11																	
Juniperus sabina	juniper									C	C														
Juniperus communis	shore juniper									B11	B11														
Juniperus conferta	shore juniper									C	C														
Juniperus procumbens	creeping juniper										C														
Juniperus silicicola	southern red cedar											B11		B11						B-2		B11			
Juniperus spp.*	cedars or junipers																								
Juniperus virginiana	red cedar																		A11	A-4		A11			B11
Kalanchoe spp.	bryophyllum												C	C	C										
Kalmia latifolia	laurel																		B11						
Krugiodendron ferreum	ironwood																				B11				
Lantana camara	common lantana			B11	B11	B11						C	[illegible]	C											
Lantana horrida	lantana					B11																			
Lantana involucrata	lantana												B11												
Lantana spp.*	lantana																								
Larix spp.	larches									C	C					C									
Larrea spp.	creosotebushes														C										
Lathyrus japonicus	beach pea	B11	B11						B11																
Lathyrus littoralis	beach pea	C						A11																	
Lathyrus maritimus	beach pea	A-8	A-10					A-5	B-5																
Lathyrus spp.	dune peas			B11																					
Lavatera assurgentiflora	tree mallow														B11										
Lechea maritima	pinweed		B11																						
Leiophyllum buxifolium	sand myrtle										B11	B11													
Leptospermum scoparium	tea tree										C	C	C												
Leucophyllum frutescens	white leaf													B11											
Ligustrum lucidum	glossy privet										C	C		C	C	C									
Ligustrum ovalifolium	privet										C														
Ligustrum spp.*	privets																								
Limonium carolinianum	sea lavender	C			A11	C						B11		B11											
Lippia nodiflora	cape weed			B11	B11	B11																			
Lithospermum caroliniense	puccoon								B11																
Lonicera involucrata	bearberry										C			C											
Lonicera morrowi	honeysuckle										C	C													
Lupinus arboreus	yellow lupine														A11	A11								B11	
Lupinus chamissonis	bush lupine						B-8								B11	B11								[illegible]	

SCIENTIFIC NAME	COMMON NAME	PIONEER ZONE								SCRUB ZONE								FOREST ZONE							
		NA	CA	SA	F	G	SP	NP	GL	NA	CA	SA	F	G	SP	NP	GL	NA	CA	SA	F	G	SP	NP	GL
Lupinus cumulicola	sand lupine			B11	B11	B11																			
Lupinus littoralis	seashore lupine							A11																	
Lupinus perennis	wild lupine								A11																
Lupinus spp.*	lupines																								
Lyonia ferruginea	stagger bush											B11		B11											
Lyonia lucida	fetter bush											B11		B11											
Lysiloma bahamensis	wild tamarind																				B11				
Magnolia grandiflora	magnolia													B11						B11		B11			
Maytenus phyllanthoides	guttapercha											B11	B11								B11				
Melaleuca spp.	melaleuca												C		C										
Mesembryanthemum aequilaterale	sea fig						A11	A11																	
Mesembryanthemum crystallinum	ice plant				C		A11	B11																	
Mesembryanthemum spp.							B11																		
Metopium toxiferum	poisonwood												B11								B11				
Metrosideros spp.	iron tree											C	C												
Monanthochloe littoralis	key grass						B11																		
Muhlenbergia capillaris	hair grass			A11	A11	A11																			
Myrica californica	wax-myrtle															A11									
Myrica cerifera	wax-myrtle											A-5	A-4	A-2											
Myrica gale	sweet gale	C								A-8	A-10														
Myrica pensylvanica	bayberry									A-2	A-1														
Myrica spp.*	myrtles																								
Nectandra coriacea	lancewood																				B11				
Nerium oleander	oleander											C	C	C	C										
Nolina tuberculata	nolina												C	C	C										
Nyssa sylvatica	black gum																		B11						
Oenothera cheiranthifolia	beach primrose							A11																	
Oenothera drummondii	evening primrose					B11																			
Oenothera humifusa	evening primrose		C	B11	B11	B11																			
Oenothera linearis	sundrops								B11																
Oenothera [illegible]	gay primrose						A11	A-7																	
Oenothera spp.*	primroses																								
Opuntia austrina	prickly pear			A-6	A-5	A-6																			
Opuntia humifusa	prickly pear										B11														
Opuntia lindheimeri	prickly pear													B11											
Opuntia occidentalis	thicket tuna														B11										
Opuntia rafinesquei	prickly pear														B11										
Opuntia serpentina	cholla						A-6		B11						B-3										
Opuntia spp.	prickly pear cacti			A11	A-7	A-5						A11	A-6	A-7											
Osmanthus americana	wild olive											A11	C	A11											
Pandanus tectorius	screwpine												C		C										
Pandanus spp.	screwpines												C												
Panicum amarulum	coastal panic grass			A11	A-4	B11	-																		
Panicum amarum	dune panic grass	B-3	A11	B-2	A-2	A-2																			
Panicum portoricense	panic grass					B11																			
Paronychia baldwinii	dune whitlow			B11																					
Paspalum caespitosum	bunch millet				B11																				
Paspalum vaginatum	[illegible] joint-grass			C		A11																			
Penstemon cordifolius	heart-leaved penstemon															B11									
Persea borbonia	red bay											B11		B-8						B-7		B-8			
Persea littoralis	shore bay											B-7		B11							B11				
Phormium tenax	New Zealand flax						C	C																	
Phyllanthus polygonoides	spurge					B11																			

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		NA	CA	SA	F	G	SP	NP	GL	NA	CA	SA	F	D	SP	NP	GL	NA	CA	SA	F	G	SP	NP	GL
Picea mariana	black spruce																	B11							
Picea sitchensis	sitka spruce																							A-11	
Picea spp.*																									
Picramnia pentandra	bittersbush																				B11				
Pinus attenuata	knob-cone pine														A41										
Pinus banksiana	jack pine																B-1								
Pinus clausa	sand pine												B11								A-1	A41			
Pinus contorta	lodgepole pine																							A-3	
Pinus elliottii	slash pine											B13	C	B11						A-5		A-1			
Pinus elliottii densa	southern slash pine												B12												
Pinus pinaster	cluster pine										C	C				C									
Pinus radiata	Monterey pine														A41								A-1	A-6	
Pinus virginiana	scrub pine																	B11	A41	C					
Pinus spp.*	pines																		B11						
Pinus strobus	white pine																B-2	B11	B11						
Pinus taeda																				B-2					
Pinus torreyana	torrey pine														B11										
Plantago pachypoda	poisonwood																				B11				
Psoralea arcuata	wild-pea											B11													
Pithecellobium guadalupense	black bead												B11												
Pithecellobium pallens	pale bead													B11											
Pithecellobium spp.													C												
Pithecellobium unguis-cati	cats-claw												B13												
Pittosporum crassifolium	kaso													C											
Poa compressa	Canada bluegrass	C						C																	
Poa secunda	one-sided bluegrass		C					C																	
Poinciana gilliesi	bird of Paradise shrub														C										
Polygonum aviculare	knotweed	B11	B11																						
Polygonum glaucum	seaside knotgrass		A41	B11		B11																			
Polygonum persicaria	smartweed							A41																	
Polygonum tenue	slender knotweed								B11																
Polypremum procumbens	June gentian			B11																					
Populus alba										B11															
Populus deltoides	cottonwood																	B11	B11						B-1
Populus spp.	aspens and poplars									C	C					C	D								
Populus tremuloides	aspen																							B11	W11
Populus trichocarpa	black cottonwood																							B-2	
Portulacaria afra	elephant bush						C																		
Prunus serrulata	flowering cherry										C														
Prosopis juliflora	mesquite													B11											
Prosopis reptans	mesquite													B11											
Prosopis spp.	mesquite													B-2											
Prunus caroliniana	laurel cherry											B11		B11						B-2		B41			
Prunus demissa	beach cherry									B11	B11														
Prunus ilicifolia	Catalina cherry														B11										
Prunus maritima	beach plum									A-2	A-2														
Prunus pumila	sand (dwarf) cherry									B-2							B-2								
Prunus serotina	black cherry									C	C						A-2								
Prunus spp.*	plums and cherries																								
Prunus virginiana	choke cherry																	B11	W11	C					C
Pseudotsuga douglasi	Douglas fir																							B-2	
Pseudotsuga taxifolia	Douglas fir																							W41	

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		NA	CA	SA	F	G	SP	NP	GL	NA	CA	SA	F	G	SP	NP	GL	NA	CA	SA	F	G	SP	NP	GL
Psilocarya nitens	shore rush			B11		B11																			
Pteridium aquilinum	bracken fern		B11																						
Pteridium latiusculum	bracken fern								B11																
Pteridium spp.	bracken fern		C	A11	B11	B11			C																
Pyracantha spp.	firethorns									C	C	C	C	C		C	C								
Pyrus arbutifolia	red chokeberry									C	A11														
Quercus agrifolia	western live oak														A11									A11	
Quercus alba	white oak																	B11	B11						B-1
Quercus chapmanii	chapman's oak											B11	B11	B12											
Quercus cinerea	blue-jack oak											B11		B11											
Quercus durata	leather oak														A11										
Quercus laevis	turkey oak																			B11		B11			
Quercus laurifolia	laurel oak																			B-7		B11			
Quercus macrocarpa																									B-5
Quercus marylandica	black-jack										B11	B11													
Quercus myrtifolia	myrtle oak											A11	A11	A11											
Quercus oleoides [illegible]	Texas live oak													B11											
Quercus rubra	red oak																	B11	B11						
Quercus spp.*	oaks																								
Quercus velutina	black oak																	B11	B11						B-2
Quercus virginiana	live oak											B11		B11						B-1	B-1	B11			
Quercus virginiana maritima	dune live oak											B-5	A-3	B-1											
Randia aculeata	white berry												B11												
Rapanea guianensis	myrsine												B11												
Raimannia humifusa	seaside evening primrose			A11		A11																			
Remirea maritima	beach star				A11																				
Reynosia septentrionalis	darling plum												B11								B11				
Rhamnus californica	coffee berry														A-2	C									
Rhus copallina	staghorn sumac										A11	A11		B11											
Rhus diversiloba	poisonwood														B11									B-7	
Rhus glabra	smooth sumac									B11	B11														B-7
Rhus leucantha	sumac												B11												
Rhus spp.	sumacs										A-7														
Rhus toxicodendron	poison oak										B11	B11		B11											
Romneya coulteri	matilija poppy						B11																		
Rosa rugosa	rugosa rose									C	A11														
Rosa spp.	roses									C	C					C	C								
Rosa virginiana	marsh rose									B-7	B11														
Rubus arenicola	sand blackberry									B11															
Rubus spp.*	blackberries																								
Rubus villifolius	blackberry															B11									
Sabal etonia	scrub fan palm											B11		B11											
Sabal minor	small fan palm											B11		B11											
Sabal palmetto	cabbage palm											A-4	A-3	A-3						A-1	A-2	A-2			
Sabina barbadensis	shore juniper												B11												
Sageretia minutiflora	rattan vine											B11													
Salicornia perennis	glasswort			B11		B11						B11													
Salicornia spp.*	glasswort																								
Salicornia virginica	glasswort	B11	B11	B11																					
Salix cordata	sandy willow									A-4	C						B11								
Salix discolor	pussywillow									A-3	C														
Salix glaucophylla	dune (low) willow										B11						B11								
Salix hookeriana	coast willow							C								A-1									

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Salix humilis	prairie willow																B11								
Salix interior	sandbar willow																B11								
Salix lasiolepis	sand willow														B11	B11									
Salix lucida	beach willow								A11								B-2								
Salix nigra	black willow																					B11			
Salix pentandra	bay-leaved willow	C	C							C	A-7														
Salix petiolaris	meadow willow																B11								
Salix sitchensis	sitka willow															B-1									
Salix spp.	willows											A11													
Salix syrticola	dune willow																A-1								
Salsola kali	saltwort	A11	A-8	A11			A-3	A11	A-4																
Sansevieria spp.				C		C																			
Sassafras varifolium	sassafras																		B11						
Scaevola plumieri	beach berry				B11							B11	A11	B11											
Schaefferia frutescens	Florida boxwood																				B11				
Schoepfia chrysophylloides	whitewood												B11												
Schinus terebinthifolius	peppertree												C												
Selaginella rupestris	club moss								B11																
Sequoia sempervirens	redwood																							B-10	
Serenoa repens	saw palmetto				B11	B-2						A-5	A-5	A11											
Sesuvium maritimum	sea-purslane										B-6														
Sesuvium portulacastrum	dune sea-purslane		C	A-7	A-2	A11						C	C	C											
Sesuvium spp.*	purslanes																								
Severinia buxifolia	box orange												C	C											
Sideroxylon foetidissimum	false-mastic																				B11				
Smilax auriculata	greenbriar											B11		B11											
Smilax bona-nox	bullbriar										B11	B11		B11											
Smilax spp.	greenbriars											A11													
Solanum dulcamara	bitter nightshade											C	C												
Solanum verbascifolium	shrub solanum											B11													
Solidago sempervirens	evergreen goldenrod	B11	A11	A11																					
Solidago sempervirens mexicana	Gulf goldenrod					A11																			
Solidago spp.*	goldenrod																								
Spartina foliosa	salt-marsh grass							A11																	
Spartina michauxiana	slough grass								B11							B11									
Spartina patens	salt-meadow grass	A11	A-4	A-2	A-2	A-4																			
Spartina spp.*	cord grasses																								
Spartina townsendii	cord grass	C	C																						
Spartium junceum	Spanish broom														B11										
Sporobolus domingensis	rush grass				B11																				
Sporobolus virginicus	rush grass			A-3	A-3	A11																			
Sporobolus wrightii	bunch grass					B11																			
Stenotaphrum secundatum	St. Augustine grass			C	C	C																			
Stipa spartea	porcupine grass								B11																
Strumpfia maritima	cedar wood												B11												
Suaeda linearis	sea-blite	C	C	C	B11	A11																			
Suaeda maritima	sea-blite	B11	B11	B11		B11																			
Suaeda spp.*	sea-blites																								
Suriana maritima	bay cedar												A11												
Swietenia mahagoni	madeira mahogany																				B11				
Tamarix articulata	tamarix													B11											
Tamarix spp.	tamarix										C	C		C	C	C									
Tanacetum camphoratum	dune tansy							A-4								B-3									

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		NA	CA	SA	F	G	SP	NP	GL	NA	CA	SA	F	G	SP	NP	GL	NA	CA	SA	F	G	SP	NP	GL
Taxus brevifolia	western yew																							B11	
Terminalia spp.	terminalias												C												
Thespesia populnea	seaside mahoe												A11								A11				
Thrinax microcarpa	brittle thatch palm																				B11				
Thrinax parviflora	thatch palm												A11								A11				
Thuja plicata	western red cedar																							B11	
Thysanella robusta	wild buckwheat			B11																					
Torrubia longifolia	longleaf blolly												B11								B11				
Tournefortia gnaphalodes	sea lavender				B11								B11												
Tradescantia foliosa	spiderwort			B11																					
Trema lamarckiana	West Indies trema																				B11				
Trifolium procumbens	hop clover		C					C																	
Trifolium spp.*	clovers		C					C																	
Tsuga canadensis	hemlock																								B11
Tsuga heterophylla	western hemlock																							B11	
Ulex europaeus	gorse										C					C									
Ulmus fulva	slippery elm																								B11
Uniola paniculata	sea oats		A-2	A-1	A-1	A-1																			
Vaccinium arboreum	sparkleberry											B-10		B11											
Vaccinium corymbosum	blueberry									B11	B11														
Vaccinium myrsinites	blueberry											B11		B11											
Vaccinium ovatum	blueberry															B11									
Vaccinium spp.*	blueberry																								
Vaccinium stamineum	deerberry										A-6														
Vaccinium vacillans	low blueberry																B11								
Viburnum lentago	sheepberry										C	C													
Viburnum spp.	[illegible]										C	C				C									
Vinca minor	periwinkle										C	C													
Vinca rosea	periwinkle											C	C	C											
Vitex agnus	chaste tree												C												
Vitis cordifolia	grape																								B-6
Vitis labrusca	grape											B11		B11											
Vitis mustangensis	muscadine grape													B11											
Vitis rupestris	sand grape										B11														
Vitis spp.	grape										A11														
Waltheria americana	coast chocolate												B11												
Washingtonia filifera	fan palm												C	C	A11										
Wedelia trilobata	[illegible]			C	C	C																			
Xanthoxylum clava-herculis	toothache tree											B11		B11											
Ximenia americana	hog plum-tallowwood											A11	A11	A11							A11				
Yucca aloifolia	Spanish bayonet			A11	A11	A11						A-9	A11	A11											
Yucca filamentosa	Adam's needle			C	C	C																			
Yucca gloriosa	mound lily												B11												
Yucca spp.	yuccas				A-9	A-8	B-4						C	C	C										
Yucca treculeana	Texas palm													B11											
Zamia integrifolia	coontie cycad												B11												
Zanthoxylum fagara	wild lime												A11								B11				
Zizyphus obtusifolia	jujube													B11											
Zoysia tenuifolia	mascarene grass				C	C																			

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